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AN INTERFEROMETER STUDY OF RADIATIONS IN A MAGNETIC FIELD. I.

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PART ONE. HISTORICAL SURVEY.

IN 1845 Faraday discovered the rotation of the plane of polarization due to a magnetic field of force. This, perhaps, suggested the further experiment as to the effect of a magnetic field upon a source of radiation placed within it.[1]

In the light of what is now known Faraday's repeated failure to obtain positive results from this last experiment may be ascribed to the low dispersive power possessed by his apparatus, and to the comparatively low temperature of the gas flame used as a source of radiation.

In 1865 Maxwell propounded the electromagnetic theory of light, which not only correlated all hitherto observed phenomena, but also furnished a scientific basis for future research.

In 1875 Professor Tait [2] presented a paper "On a Possible Influence of Magnetism on the Absorption of Light" which, while not realized by him experimentally is of interest in this connection. He says in part:

"The explanation of Faraday's rotation of the plane of polarization of light by a transparent diamagnetic requires, as shown by

[1] Appendix I.

[2] Proc. Roy. Sec. Edinburgh. Sessions 1875–76, p. 168.

Thomson,[1] molecular rotation of the luminiferous medium. The plane polarized ray is broken up, while in the medium, into its circularly polarized components, one of which rotates with the ether so as to have its period accelerated, the other against it in a retarded period. Now, suppose the medium to absorb one definite wave-length only, then—if the absorption is not interfered with by the magnetic action—the portion absorbed in one ray will be of a shorter, in the other, of a longer period than if there had been no magnetic force; and thus, what was originally a single dark absorption line might become a double line, the components being less dark than the single one."

The line of reasoning here presented, if applied to a source of radiation (instead of absorption) placed in a magnetic field would give an analogous solution of two bright lines of less intensity than the original line.

The first experimental results in this field of work were obtained by M. Fievez[2] in 1885–86. His observations consisted in a broadening of the spectral line, and increased brilliancy of illumination. No observations are recorded as to the state of polarization.

The phenomena of reversal and increased brightness of the lines, while undoubtedly precipitated by the action of the magnetic field, were probably due, primarily, to changes of temperature and density. The broadening of the line, however, was undoubtedly a genuine magnetic effect, and as Preston[3] remarks, had Fievez been acquainted with the theory of the subject the whole question would have been settled in 1885.

Fievez does not seem to have been familiar with what Faraday had done as regards the state of polarization, nor to have taken any special precautions against spontaneous reversals: yet, while his work may, in the light of recent investigations, appear meager, it deserves an important place in the history of the subject, and must sooner or later have led to the very results reached by Zeeman.

A paper entitled "Causes of Double Lines and Close Satellities

[1] Reprint Thomson's Papers on Electrostatics and Magnetism. Second Edition, p. 423, Footnote.

[2] Appendix II.

[3] Phil. Mag. (5), 45, 1898, p. 338.

in the Spectra of Gases," by G. J. Stoney,[1] though not considering the special case of magnetic forces, has, nevertheless, a theoretical bearing upon the subject.

Of still greater importance are the writings of Lorentz,[2] published in 1892 and 1895, inasmuch as they were a guide to Zeeman in his experiments.

In March, 1897, Dr. P. Zeeman[3] communicated to the Philosophical Magazine the results of a research that has proved wonderfully fruitful in his own hands and also in the hands of others. Zeeman was familiar with Faraday's experiments, but did not know of Fievez's work. He was influenced, as a matter of course, by Maxwell's electromagnetic theory of light, and in particular was guided by Lorentz's exposition of it. His first experiments were identical with those of Faraday, excepting that he had a Rowland grating of 14,000 lines to the inch, and hence had a much greater dispersion. With this arrangement of the apparatus, a broadening of the spectral line was observed, similar to that seen by Fievez. Guided, however, by Lorentz's theory, Zeeman tested the state of polarization of the broadened line, and found that, when viewed parallel to the lines of force, the edges of the line were circularly polarized as predicted by Lorentz's theory.

Lorentz's Theory.—In this theory it is assumed that light vibrations are the vibrations of electrically charged ions of definite mass. Thus suppose such an ion having a charge e and mass m, to vibrate with simple harmonic motion about its center of equilibrium. Such an ion moving in a magnetic field would then experience mechanical forces, which would cause a change of period of vibration. The amount of this change of period would depend upon the ratio e/m, and the measurement of the change of period would give a knowledge of this ratio.

The equations giving the modified period are derived as follows.[4]

In Fig. 1 let the origin be at O and the axis of Z be parallel to

[1] Sci. Trans. Roy. Dublin Soc., Vol. IV., p. 563, 1891.

[2] Lorentz, "La Theorie electromagnetique de Maxwell." Leyden, 1892. "Versuch einer Theorie der electrichen und optischen Erscherungen in bewegten Korpern." Leyden, 1895.

[3] Phil. Mag. (5), 43, p. 226. Same art. Astro. Phys. Jr., 5, p. 332, 1897.

[4] See Zeeman, Phil. Mag. (5), 43, p. 226.

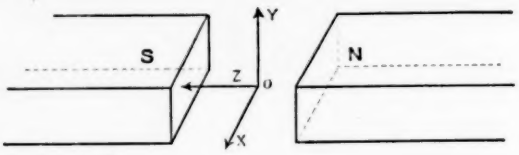

Fig. 1.

the lines of force, the axes of X and Y being perpendicular to this direction. Then if H be the strength of field, the equations of motion relative to the X and Y axes are

$$\left.\begin{aligned} m\frac{d^2x}{dt^2} &= -K^2x + eH\frac{dy}{dt} \\ m\frac{d^2y}{dt^2} &= -K^2y - eH\frac{dx}{dt} \end{aligned}\right\} \qquad (1)$$

The term K is the coefficient of elasticity of the ion, the second term gives the mechanical force due to the magnetic field.

The solution of these equations yields for the period of vibration the following values:

$$\text{If} \quad H = 0, \quad T = \frac{2\pi\sqrt{m}}{K} \qquad (2)$$

If H be not zero, and we regard all forces in the XY plane as symmetrcial with respect to the axis of Z, then

$$T' = \frac{2\pi\sqrt{m}}{K}\left(1 \pm \frac{eH}{2K\sqrt{m}}\right). \qquad (3)$$

The meaning of equations (2) and (3) is as follows:

If we analyze along the three coördinate axes, the motion of the moving ion, which by virtue of this vibration is emitting light, we shall have three component vibrations of equal period. We may next compound the two components which lie in the XY plane into circular motion, and since we do not know the sense of rotation, we may conceive it to be in both directions simultaneously.[1]

If the source of light be viewed in a direction parallel to the magnetic field, the component whose motion is parallel to the axes of Z is not effective, and the ray is, therefore, composed of circularly

[1] The sense of rotation will depend upon the sign of the charge e upon the iron.

polarized components, whose periods of rotation are the same, and for zero magnetic field have the value given by equation (2). If the magnetic field be equal to H, then the periods become changed, and are given by equation (3). The periods being changed by equal and opposite amounts, the original spectral line becomes two lines of equal intensity, symmetrically situated with respect to the original unmagnetized line; the components being circularly polarized in opposite senses.

Viewed in a direction normal to the magnetic field, the component parallel to the axis of Z, and, therefore, parallel to the axis of the magnetic whirl, is not affected by it, is unaltered in period and appears as a plane polarized ray. The two circular components, being now viewed parallel to the $X\,Y$ plane, also appear as plane polarized rays, the plane of polarization being normal to that of the Z component.

Thus viewed, the spectral line is broken up into *three* component lines, and if the magnetic field is of sufficient intensity there will be seen *three* distinct lines, the two outlying ones having their vibrations in a plane normal to the magnetic field, and the central one in a plane parallel to it. If the magnetic field is not powerful enough to separate the three components they will overlap, and the line appears merely broadened. The components may, however, be isolated by means of a nicol prism.

In his earlier work[1] Zeeman obtained only a broadened line, but by means of the nicol he was able to test the state of polarization; and, later,[2] he succeeded in obtaining both the doublet parallel to the magnetic field, and the triplet normal to the field, as predicted by Lorentz's theory.

Methods.—In the further progress of the work two radically different methods have been developed.

The first is that followed by Zeeman and many other investigators. It consists in photographing the spectral lines, and in measuring the separation of the "magnetized" components by means of the micrometer dividing engine. The chief merit of this method is that a permanent record is secured in the photograph. It is also

[1] Phil. Mag. (5), 43, p. 226.
[2] Phil. Mag. (5), 44, pp. 55 and 255; 45, p. 197.

an advantage that the phenomenon is observed directly. The limitations of the method are: *First*, the fact that the quantity to be measured is minute, and the micrometer method of direct measurement is of necessity limited in range; *Second*, it frequently happens that the components, whose distances apart are to be measured, are so nebulous as to make it exceedingly difficult to make exact micrometer settings. *Third*, the time of exposure necessary is sometimes so long as to make the method prohibitory.

The second method is due to Professor A. A. Michelson, and may be called the *Interferometer Method*. It has been used successfully with magnetic fields far too weak to give any sensible effect by the direct method, and has been shown to have a delicacy and sensitiveness far in excess of any photograph. The method, as used by Professor Michelson, consists in obtaining the visibility curves of the spectral line, both when unmagnetized, and also with fields of different intensity. These visibility curves are then analyzed,[1] and the distribution of light at the source of illumination obtained. This gives directly the various "magnetic" components of the line: By means of a nicol prism the two planes of polarization may be separately examined.

The advantages of this method are—briefly—*First*, the visibility curve enables the separation of lines not hitherto resolved by any other method. *Second*, the eye is the instrument of investigation, and hence there is no need of long exposure as in the case of taking photographs. *Third*, any change of polarization—or other effect—taking place during the period of observation may be detected, while the photographic process is necessarily an integrating method.

The disadvantages are: *First*, the method is an indirect one, *i. e.*, the observations are made not on the lines themselves but on interference fringes produced by them. *Second*, the accurate estimate of a visibility curve is by no means an easy matter, and the rare success attained by Professor Michelson has been equalled by no one else, and can only be approached by practice and great patience. *Third*, the record of the instrument is not automatic, as in the photograph, and is subject to the personal error of the observer. *Fourth*, the reflection from the half silvered surface of the in-

[1] Phil. Mag. (5), 34, p. 280, 1892. Astro. Phys. Jr., 7, p. 129, 1898.

terferometer affects the two beams polarized in perpendicular planes, to a different degree, so that when both beams are simultaneously observed they have not their normal ratio of brightness, with the result that the fringes are correspondingly deceptive.

In the hands of an experienced observer the interferometer is undoubtedly the most powerful instrument of attack that is available at present, unless, indeed, Professor Michelson has presented in the Eschelon Plate Spectroscope, an instrument of equally great value. Under circumstances less favored than those enjoyed by Professor Michelson, it is difficult to see how the Interferometer Method as he uses it, can be successfully used. There are, however, modifications rendering this instrument more available, which have been used by the present writer.

Experimental Results.—The agreement between theory and experiment presented by Zeeman's early experiments was truly remarkable, and the apparent simplicity of the phenomenon seemed equally worthy of notice. This apparent simplicity, however, was soon found not to be true of all spectral lines, and more complex forms were found. Exceptions were also found to the state of polarization as first described by Zeeman.

The first observer to note a departure from the normal form was M. Cornu.[1] His apparatus was similar to that of Zeeman excepting that he used a double image prism, and was thus able to observe both planes of polarization simultaneously. For a magnetic field strength of 13,000 C. G. S. units he observed that the sodium line, D_1 when viewed normal to the magnetic field was a quadruple, the inner components being polarized perpendicular to the magnetic field and the outer ones parallel to this direction. The line, D_2 he found to be a hazy triple with each member perhaps doubled.

M. Cornu was soon followed by others. Preston[2] succeeded in photographing as many as five different types, and Michelson[3] with the interferometer showed three well marked groups of lines.

As regards polarization Becquerel and Deslandres[4] have found

[1] Astro. Phys. Jr., 6, p. 378, 1897; 7, p. 163, 1898.

[2] Phil. Mag. (5), 45, p. 330, 1898; 47, p. 165, 1899.

[3] Phil. Mag. (5), 44, p. 109, 1897, same Art. Astro. Phys Jr., 6, p. 48, 1897; Phil. Mag. (5), 45, p. 348, 1898, same Art. Astro. Phys. Jr., 7, p. 131, 1898.

[4] C. R., April 4, 1898.

that one of the iron lines when viewed perpendicularly to the magnetic field becomes a triple, in which the usual state of polarization is reversed. The same phenomenon has also been observed at the Johns Hopkins [1] University.

The classification of lines as given by Preston is shown in Fig. 2, who thus describes them.

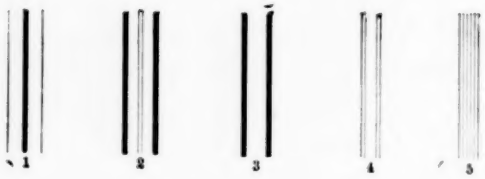

Fig. 2.

"In 1 we have the normal triplet. In 2 we have the weak middled 'quartet' in which nearly all the light is concentrated in the two side lines. Next we have in 3 the doublet in which the central line has completely disappeared. Next in 4 we have the double doublet, or two pairs of fine lines, and finally in 5 the sextet or three pairs of equally spaced sharp lines."

Preston [2] cites the following as examples of the above types Type 1, Cd, 4678; Mg, 5167; Zn, 4680 and the vast majority of other lines. Type 2, Mg, 5183; Cd, 5086; Zn, 4810. Type 4, Mg, 5173; Cd, 4800; Zn, 4722. In his latest work [3] Preston seems to restrict his classification to three types, viz.: "Diffuse triplets," "quartets" and "pure triplets." It may be that types 3 and 4 are modified forms of the same type, as also 2 and 5. This would leave but three types.

The types found by Michelson [4] are shown in Fig. 3. The upper curves are taken by the interferometer and the lower by the Echelon plate spectroscope. The spectral lines are viewed normal to the magnetic field in both figures 2 and 3.

[1] Astro. Phys. Jr., 8, p. 48, 1898.

[2] Phil. Mag. (5), 45, p. 330.

[3] Phil. Mag. (5), 47, p. 178. See also Nat., Vol. 59, p. 226, where seven types are given.

[4] Astro. Phys. Jr., 7, p. 136, 1898. Nat., March 9, 1899.

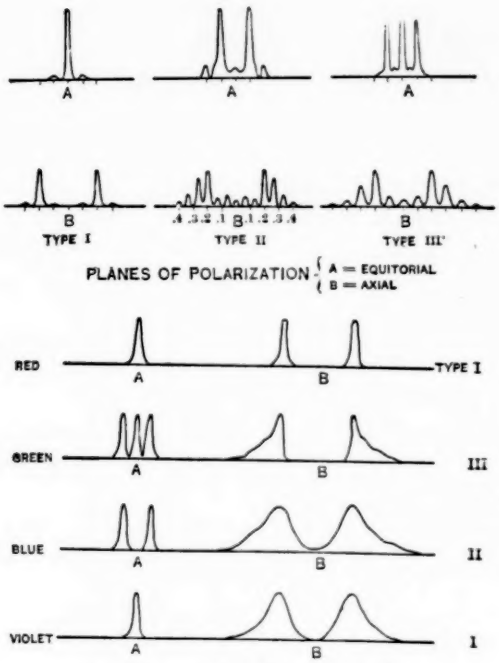

Fig. 3.

The following are some examples:

Type I.	Type II.	Type III.
Hg yellow line.	Hg violet line.	Hg green line.
Cd red line.	Cd blue line.	Cd green line.
Zn red line.	Zn blue line.	Mg green line (5183).
Au green line.	Na yellow line.	
Ag yellow line.	Au yellow line.	
Ag green line.		

Michelson adds a fourth type in which a broad or complex line is simplified or narrowed in the magnetic field. Examples of this are Cu yellow line and Mn green line (5340). This effect is true of the central member of the triplet in the case of these two lines.

If now a comparison be made between such lines as have been observed by several persons the following rather meager data are found.

TABLE I.

Lines.	Type.	Field Strength.	Observer.
Zn. 4810.	Diffuse triplets.	———	Preston.
" "	Type II	10,000.	Michelson
Cd. 5086.	Diffuse triplets.	———	Preston
" "	Type III.	10,000.	Michelson.
" 4800.	Quartets.	———	Preston.
" "	Type II.	10,000.	Michelson.
Na. D_1	Type II.	10,000.	Michelson.
" "	Quartet.	13,000.	Cornu.
" D_2	Type II.	10,000.	Michelson.
" "	Sextet.	13,000.	Cornu.

The results of such a comparison are of little value, unless the conditions as regards the source of radiation and the magnetic field strength are known to be the same. Two things are, however, apparent.

I. The phenomenon is by no means as simple as was at first supposed by Zeeman.

II. The superiority of the Interferometer Method as regards resolving power is shown.

Modified Theories.—Having found that the extremely simple deductions from Lorentz's theory, as made by Zeeman, do not comprehend the observed phenomena, it becomes necessary, either to present a new hypothesis or suitably to modify the old one. This modification has been made by Lorentz,[1] Larmor[2] and others, while Preston[3] has pointed out that the paper of Dr. Stoney,[4] already cited, anticipates the desired theory.

Dr. Stoney considers the effect of perturbing forces upon an ion, moving in an elliptical orbit under the action of a central force, which is proportional to the distance. If the perturbing force be such as to cause the orbit to rotate in its own plane, then the spectral line becomes a doublet. Thus if the ion be moving with an

[1] Proc. Roy. Acad. Sci. Amsterdam, June 25, 1898. Also Astro. Phys. Jr., 9, p. 37. Wied. Ann., Bd. LXIII., p. 278, 1897.

[2] Phil. Mag. (5), 44, p. 503.

[3] Phil. Mag. (5), 47, p. 171.

[4] Trans. Roy. Soc. Dublin, Vol. IV., p. 563. See also Preston, Phil. Mag. (5), 47, p. 171.

angular velocity Ω then $\Omega = 2\pi N$ where N is the frequency of the rotation. If now an angular velocity of ω be impressed upon the system as a whole, and in the same plane as Ω, then the resultant angular velocity is the algebraic sum of the two. The resultant frequency will also be the algebraic sum; and since Ω is to be regarded in both senses, the resultant motion will have a double frequency of $N + n$ and $N - n$.

Viewed dynamically the equations show what forces are necessary to produce the above changes. If the ion rotate with an angular velocity Ω, and the orbit itself rotate about an axis passing through the center of force, and having a direction (lmn) with an angular velocity ω, then the component velocities referred to the rotating orbit are

$$\left.\begin{aligned} u &= \frac{dx}{dt} = -\omega ny + \omega mz \\ v &= \frac{dy}{dt} = -\omega lz + \omega nx \\ w &= \frac{dz}{dt} = -\omega mx + \omega ly \end{aligned}\right\} \tag{4}$$

The component accelerations are

$$\left.\begin{aligned} \frac{du}{dt} &= -\omega nv + \omega mw \\ \frac{dv}{dt} &= -\omega lw + \omega nu \\ \frac{dw}{dt} &= -\omega mu + \omega lv \end{aligned}\right\}. \tag{5}$$

Expanding equation (5) from equation (4) the acceleration along the axis of X is

$$\frac{du}{dt} = \frac{d^2x}{dt^2} = -\omega n\frac{dy}{dt} + \omega m\frac{dz}{dt} - \omega n\left(\frac{dy}{dt} - \omega lz + \omega nx\right) + \omega m\left(\frac{dz}{dt} - \omega mx + \omega ly\right)$$

which, by adding the term $\omega l(\omega lx - \omega lx)$ and remembering that $l^2 + m^2 + n^2 = 1$, reduces to

$$\frac{d^2x}{dt^2} = -2\omega\left(n\frac{dy}{dt} - m\frac{dz}{dt}\right) - \omega^2 x + \omega^2 l(lx + my + nz).$$

Two similar expressions give the acceleration along the Y and Z axes.

The total acceleration experienced by the ion is then

$$\begin{aligned} X &= -\Omega^2 x - \frac{d^2x}{dt^2} = -\Omega^2 x + 2\omega\left(n\frac{dy}{dt} - m\frac{dz}{dt}\right) \\ &\quad + \omega^2 x + \omega^2 l(lx + my + nz) \\ Y &= -\Omega^2 y - \frac{d^2y}{dt^2} = \text{etc.} \\ Z &= -\Omega^2 z - \frac{d^2z}{dt^2} = \text{etc.} \end{aligned} \qquad (6)$$

In the case of a magnetic field of force, if the axes of Z be taken parallel to the magnetic field then (l, m, n) become equal to (0,0,1) and equations (6) reduce to

$$\left.\begin{aligned} X &= -\Omega^2 x + \omega^2 x + 2\omega\frac{dy}{dt} \\ Y &= -\Omega^2 y + \omega^2 y - 2\omega\frac{dx}{dt} \\ Z &= -\Omega^2 z \end{aligned}\right\}. \qquad (7)$$

Now the central force producing the original rotation is $\Omega^2 x$. The perturbing forces are then represented by the terms $\omega^2 x + 2\omega\frac{dy}{dt}$ and $\omega^2 y - 2\omega\frac{dx}{dt}$. Examining these it is seen that $2\omega\frac{dy}{dt}$ and $-2\omega\frac{dx}{dt}$ are the X and Y components of a force $2\omega v$ acting perpendicularly to v, the linear velocity of the ion. If then a charged ion move in a magnetic field with a velocity v, $2\omega v$ is the force it would experience due to the magnetic field. The terms $\omega^2 x$ and $\omega^2 y$ represent centrifugal forces due to the impressed velocity ω, and in the first approximation may be neglected. Finally, if $K = 2\omega$, the above equations become identical with those of Lorentz.

Equations (6) and (7) are sufficiently general to cover all hitherto observed phenomena. Thus to explain the case where

the central line of the triplet (line 2, Fig. 2) is doubled, it is only necessary to write the equation for Z in the form $Z = A \sin \Omega t$ where A is a periodic function of t of the form $A = a \sin nt$. Substituting this in the equation $\frac{d^2z}{dt^2} = -\Omega^2 z$ and integrating we get

$$Z = a \sin nt \sin \Omega t = a/2 \left[\cos (\Omega - n) t - \cos (\Omega + n) t\right],$$

which represents two vibrations of frequency

$$(\Omega \pm n)/2\pi. \tag{8}$$

The case of reversed polarization may be covered by supposing the value of n to be such as to separate the components sufficiently to place them outside the other lines of the triplet. In a similar manner the doubling of the outer members of the triplet may be accounted for which would also cover the case of a quartet when viewed parallel to the magnetic field. In this way all the various cases of multiple lines are satisfactorily explained.

Reverting to equations (2) and (3) we see that the change of period of the ion is expressed by the equation,

$$T - T' = \frac{2\pi\sqrt{m}}{K} \cdot \frac{eH}{2K\sqrt{m}}.$$

The proportional change will then be

$$\frac{T - T'}{T} = \frac{eH}{2K\sqrt{m}} = \frac{e}{m}\frac{HT}{4\pi}$$

since

$$K = \frac{2\pi\sqrt{m}}{T}.$$

Finally, since $T = \frac{\lambda}{v}$ and $T' = \frac{\lambda'}{v}$ where v = velocity of light, this becomes

$$\frac{\lambda - \lambda'}{\lambda^2} = \frac{e}{m}\frac{H}{4\pi v}. \tag{9}$$

Where λ = wave-length of the spectral line for zero magnetic field.
λ' = wave-length of the spectral line with magnetic field.
v = velocity of light, 300,000,000 cm.
H = intensity of magnetic field in C. G. S. units.

Equation (9) may be written

$$\frac{e}{m} = \frac{\lambda - \lambda'}{\lambda^2} \frac{4\pi v}{H} \tag{10}$$

and it is seen that a measurement of the change of wave-length enables us to determine the ratio of the ionic *charge* to the ionic *mass*.

Zeeman[1] finds for this ratio, in the case of the blue line of Cd ($\lambda = 4800$) 24×10^6, while Preston[2] has found that this value must be determined separately for each line, but that a possible classification of lines may be made similar to the chemical classification of Keyser and Runge.[3]

Another interesting and significant observation is that of Ames[4] et. alt. who find that in the case of some iron lines, there appears to be no magnetic effect, while those lines which show the greatest magnetic shift are the ones which show the greatest pressure shift, aud those which show but little magnetic shift are the ones of little pressure[5] shift.

The present status of the subject may be summarized as follows:

1. In general, spectral lines are influenced by the magnetic field when the radiations emanate from a source of light in the magnetic field.[6] The magnetized system of lines is symmetrical with respect to the original unmagnetized line. New spectral lines may be produced by the magnetic field.[7]

2. Viewed parallel to the magnetic field the spectral line is, in general, doubled, but it may become a single or multiple line. In the case of a single line there is no polarization;[8] in all other cases the components are circularly polarized; the shorter wave-length in the direction of the magnetizing current, the longer wave-length in the opposite sense.

3. Viewed in a direction perpendicular to the magnetic field the

[1] Acad. Amsterdam, 1897-1898, p. 260.
[2] Phil. Mag. (5), 45, p. 337.
[3] Wied. Ann., Bd. XLIII., p. 394, 1891.
[4] Astro. Phys. Jr., 8, p. 50, 1898.
[5] Astro. Phys. Jr., 6, p. 169, 1897.
[6] Astro. Phys. Jr., 8, p. 49.
[7] Astro. Phys. Jr., 9, p. 47.
[8] This would be true of the lines seen by Becquerel and Ames, showing reversed po'arization, when viewed parallel to the magnetic field.

outer components are plane polarized so that their vibrations are perpendicular[1] to the magnetic field ; the inner components having their vibrations parallel to the magnetic field.

4. The general form of the line viewed perpendicularly to the magnetic field is a triplet, but it is sometimes of complex structure.

5. The amount of magnetic action, measured in change of period of the spectral line, is not a simple function of the wave-length ; nor is it a constant for all wave-lengths ; nor a constant for all lines of a given substance ; nor is it a simple function of wave-length for the lines of a given substance.

6. The magnetic action is proportional to the field strength (being limited, however, by temperature and pressure) ; and there appears to be a possible classification following the chemical classification of Mendelejeff and of Kayser and Runge.

Part Two. Experimental Work.

Introductory Note.—From the foregoing survey of the subject we are led to believe that a comprehensive study of the problem consists essentially of two parts :

1. A qualitative analysis of as many spectral lines, emanating from as many different substances as possible, with a classification according to the type of line produced.

2. Quantitative measurements of the change of wave-length and of the ratio e/m, and a classification based upon these measurements.

All spectral lines belonging to the same group in both classifications may then be regarded as possessing related properties, and the ratio e/m as determined from such a group of lines should have the same value.

Such a series of observations would as Preston remarks " afford a valuable means of inquiry into the so far hidden nature * * * of the radiation from a luminous body, and also give us some clearer insight into the structure of matter itself."

Outline of Work.—In the following research the complete study of the subject was not attempted, this being manifestly too great a task for the limited time available. The preliminary ground has, however, been cleared and a beginning made.

[1] Exception, see Astro. Phys. Jr., 8, p. 50, 1898.

The work was subdivided as follows:

Section I. A preliminary survey of the field with a view of determining the conditions limiting the observation of the magnetic phenomenon.

Section II. A comparison of the ease of manipulation and range of the two methods outlined above.

Section III. To ascertain whether the magnetic effect is radically different at different temperatures.

Section IV. To measure the magnetic shift of as many lines as the time available would permit; studying, also, the state of polarization of the components.

SECTION I. A PRELIMINARY SURVEY TO DETERMINE THE CONDITIONS LIMITING THE OBSERVATION OF THE MAGNETIC PHENOMENA.

APPARATUS. I. *Magnet.*—This was of the usual upright type; the base, cores, coils, pole heads, and cores to pole heads are all separable; the base and cores to the pole heads are of mild steel, the rest of the magnetic circuit being made of that form of cast iron known as *Mitis Metal.* An elevation of the magnet is shown in Fig. 4, drawn to $\frac{1}{8}$ scale.

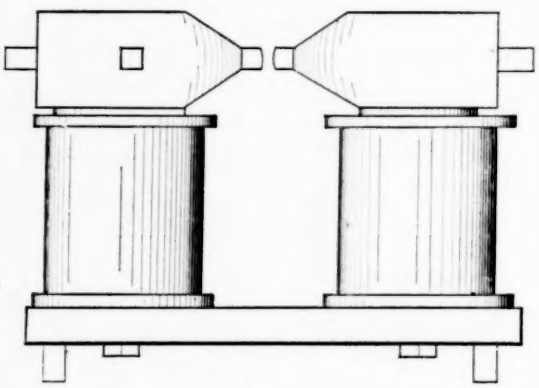

Fig. 4.

The cores to the pole heads are one inch in diameter, and it soon became apparent that they, together with the mass of iron behind them, tended to lower the temperature of the flame. A second

pair of cores was made of the form shown in Fig. 5. This form also concentrated the magnetic field, thereby increasing its strength. A third core was prepared similar to those shown in Fig. 4, with a ¼-inch hole throughout its length; this core was for use in viewing the flame parallel to the magnetic field.

Fig. 5.

II. *The Flame.*—The flame of a small Bunsen burner was first used but was found to be too large. A small blast lamp was then made of glass, and a foot bellows used. This gave a small conical jet of flame about 3 inches high when the blast was inactive, and about ¾ inch high with the blast. This form of lamp, shown in Fig. 6, proved highly satisfactory.[1]

To color the flame a strip of asbestos wick supported by platinum wire was first used. A bead of fused sodium carbonate was also used, and, finally, a rod of sodium glass was adopted as needing the least attention. When a very bright flame is used recourse to the fused bead may be had, but such a flame generally gives rise to spontaneous reversals. In the latter experiments the glass lamp was set aside for the burner of an oxy-hydrogen lamp, and the foot-blast was replaced by an oxygen tank.

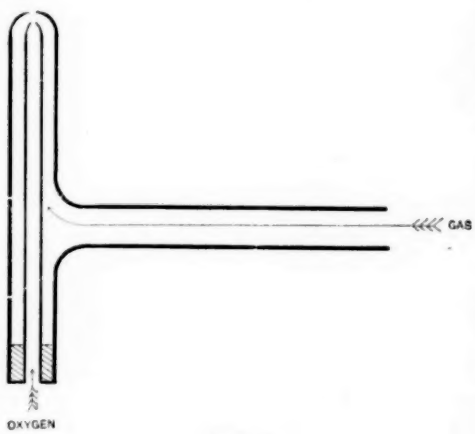

Fig. 6.

III. *Dispersion Apparatus.*—The first trials were made with a plane grating spectroscope; the higher spectra were especially dim. No success was attained with this apparatus. Next a Rowland concave grating of 14,436 lines to the inch and five feet focal distance was mounted at one end of the table, the magnet being at the other end. The spectrum was viewed with a telescope. It was

[1] In time the glass about the opening cracks away but the whole lamp is easy of construction.

with this mounting and with an oxygen gas flame that the first results confirmatory of Zeeman's work were obtained.

The arrangement of apparatus is shown in Fig. 7. The lines D_1 D_2 were very sharp and bright. When the current was turned

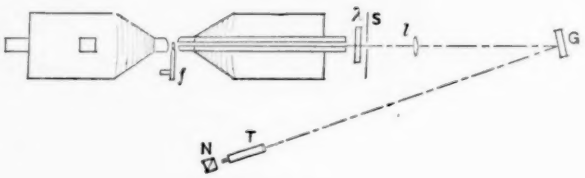

Fig. 7.

on each line grew broad and after a few seconds became distinctly double, a sharp dark line separating the components throughout their whole length. The lines were visibly brightened, as was also the whole flame.

When the current was interrupted the lines appeared to collapse, and after a second or so would again become sharp. Frequently the doubling of the lines would persist for a few seconds after the current was broken and the dark dividing line could be seen, though narrower than with the full field.

For the doubling a field strength of about 18,000 C. G. S. units was used, with weaker fields only a broadening of the line could be observed.

Polarization.—With zero field the light was found to be slightly polarized by reflection from the grating. The polarization with full field is represented in Fig. 8, the accelerated components D_1^2, D_2^2 harmonize in their sense of rotation with the magnetizing current. The $\frac{1}{4}$ λ plate reduces the circular polarization to plane polarization.

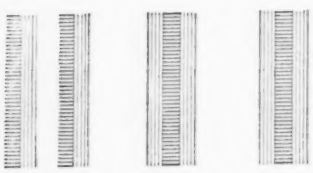

Fig. 8. Fig. 9.

Viewing the flame in a plane perpendicular to the magnetic field the pole cores shown in Fig. 5 were used. The tripling can best be observed by means of the nicol; without the nicol the tripling could be faintly seen, but the strength of field necessary and the instrumental difficulties present make the

observation of the phenomena far from satisfactory. The planes of vibration of the components are shown in Fig. 9. As no quarter wave plate is used this is the state of vibration in the ray of light itself.

It being apparent that no measurements could be taken without resorting to photography, the study was concluded at this point and work with the interferometer begun.

Summary. The following points may be noted as covering the first point aimed at in the work :

1. The magnetic separation of the sodium lines D_1 D_2, as given by a naked flame, cannot be distinctly observed at the temperature of the Bunsen flame, nor of the air-blast flame, nor even at the temperature of the oxygen gas flame, unless precautions are taken against spontaneous reversals.

2. The phenomenon can be much more satisfactorily observed parallel to the magnetic field when perpendicular to it, as the strength of field necessary to produce a pure (or visual) triplet is twice that necessary to produce the doublet.

3. There is a very perceptible time lag both when the magnet is excited and when the current is broken, during which period the lines show an inertia effect. This lag does not seem to be wholly due to the self-induction of the fields, but may be partially visual and partially *ionic*.

4. A field strength of at least 15,000 C. G. S. units seems to be necessary for satisfactory observation.

5. Spectra above the second order are too faint for good effects.

PHYSICAL LABORATORY,
UNIVERSITY OF WISCONSIN, April, 1899.

To be continued.

THE ELECTRICAL RESISTANCE OF LEAD AMALGAMS AT LOW TEMPERATURES.

BY GEORGE W. GRESSMAN.

THE purpose of the work described below was two-fold: to determine the temperature coefficient for resistance of some of the lead amalgams, and to locate their freezing points by means of the great decrease in resistance that occurs when the amalgam passes from the liquid to the solid state. Although the work is not yet completed, nor even entirely satisfactory, the results obtained seem of sufficient interest to warrant publication.

So far as the writer has been able to learn, no attempt prior to this has been made to determine the temperature coefficient for lead amalgams. G. Tammann[1] and D. Mazzotto,[2] however, have determined the freezing point of many lead amalgams. Unfortunately the articles by Mazzotto are not at my disposal, so that no comparison can be made with his results. Since the amalgams considered in this paper, with one exception, contain from four to twenty-five per cent. of lead, merely a qualitative comparison can be made with the results obtained by Tammann, as he experimented only with dilute amalgams. Still, the two sets of experiments do supplement each other and show that, in general, lead amalgams have a higher freezing point than pure mercury. Neither are lead amalgams the only exceptions to the general law that a solution has a lower freezing point than the solvent. Tammann found that cadmium, gold, and tin amalgams agree with the lead amalgams in this respect, while Van Bylert has shown that a rise in the freezing point occurs in solutions of antimony in tin; other writers have found similar results for naphthal in napthalene and carbazol in phenanthrene.

J. H. Van't Hoff[3] explains this rise in the freezing point as prob-

[1] Zeitschrift für Physikalische Chemie, Band 3, 1889.

[2] Estratto d. atti d. Istituto Veneto d. sc. lettere ed. arti, 1892–93.

[3] Berichte d. deutsch. chem. Gesellschaft., 27, 1894.

ably due to the fact that the dissolved substance and the solvent, are frozen out together. He says: "If the solvent upon being frozen is able to carry down some of the dissolved body, its vapor pressure diminishes and the freezing point correspondingly rises."

Preparation of Amalgams.

The mercury that entered into the composition of the amalgams had been distilled and afterward cleansed by passing slowly first through concentrated sulphuric acid, and then through mercurous sulphate. Most of the lead was such as is ordinarily furnished as chemically pure. The percentage of lead in each amalgam was obtained by weighing the lead and mercury separately, and then computing the number of parts of lead in one hundred parts of the solution. Since the amalgams were, for the most part, prepared by fusing the lead and then adding the mercury after the lead had cooled down nearly to the point of solidification, the percentages given are subject to a slight error due to the vaporization of a small fraction of the mercury upon adding it to the heated lead.

All apparatus brought in direct contact with the amalgam or either constituent was cleansed with nitric acid, rinsed with alcohol, and thoroughly dried. Hence the amalgams can be considered free from impurities.

Apparatus.

The amalgams were contained in small U-tubes, varying from 1 to 2 mm. in diameter, being expanded at the ends sufficiently, however, to insert suitable terminals. Closely around this tube, from end to end, was wound a small coil of copper wire, by means of which the temperature was measured. After the tube had been filled with the amalgam, it was immersed in a test tube containing glymol. This prevented the temperature wire from coming in direct contact with the freezing mixture, and also protected against too sudden changes of temperature. The test tube was placed inside of another tube containing ether, into which solid carbon dioxide could be introduced in small quantities, thus gradually reducing the temperature below the freezing point of the amalgam. In order to preserve the freezing mixture, the tube containing it was enclosed by an air space filled lightly with mineral wool, to prevent convec-

tion currents, and then surrounded by a cooling bath of ice and snow.

MEASUREMENT OF RESISTANCE.

Since this work is concerned with resistance only so far as it depends upon the temperature, all resistances were measured in terms of an arbitrary standard by the fall of potential method. The standard resistance consisted of a small coil of German silver wire carefully wound with asbestos paper to protect it from sudden changes of temperature. As the temperature of the room never changed to any considerable extent during a single experiment, and in addition, the temperature coefficient of the German silver wire is approximately one-tenth that of the copper wire, any variation in the resistance of the standard wire, due to the slight change in the temperature, was negligible.

A sensitive galvanometer, having a resistance about one thousand times as large as the unknown resistance, was used to measure the fall of potential. Hence by connecting the amalgam, the temperature wire, and the standard resistance in series, three galvanometer readings were sufficient to determine the temperature and resistance of the amalgam at any time ; for the ratio of the fall of potential in the amalgam or temperature wire to that in the standard resistance will give the corresponding resistance in terms of this standard.

In order to eliminate the error which might arise from a lag in the amalgam taking on the temperature of the copper wire, the solid carbon dioxide was added in small quantities, so that measurements could be made during the process of cooling down as well as that of warming up. Furthermore, time was recorded in all cases, and an effort was made to have the warming up take place with the same rapidity as the cooling down. In general, the amalgams warmed up along the same curve as they had cooled down, but when there was any discrepancy the curve was drawn through the mean.

REDUCTION TO CENTIGRADE SCALE.

For the purpose of converting "copper degrees" into degrees centigrade, the temperature coefficient of a specimen of the copper wire was carefully determined in connection with Mr. A. H. Thies-

sen.[1] Tests were also made with the exact piece of wire used in measuring the temperature, and the average value obtained was .00405. At first an attempt was made to wind the copper wire on the tube, and then calibrate it by means of direct observations and the temperature coefficient. Thus the temperature corresponding to any resistance of the copper wire could have been read directly from a calibration curve, which would have rendered it a fairly convenient thermometer. This project was soon found to be impracticable, owing to the fact that the absolute resistance of the temperature wire was not constant, since it was frequently broken when cleaning the tubes, and also different lengths were used upon different tubes. Consequently, the temperature of the wire was accurately measured to tenths of a degree by a mercury thermometer at the beginning of each experiment. Then, knowing the temperature coefficient, the resistance of the wire at 0°C. can easily be obtained from the equation

$$R_t = R_0(1 + \alpha t),$$

from which

$$R_0 = \frac{R_t}{1 + \alpha t}$$

where R_t is the resistance of the wire at t°C., R_0 the resistance at 0°C., and α the temperature coefficient. The equation also shows that the change of resistance per degree centigrade is $R_0\alpha$. Hence, knowing the temperature coefficient and the temperature at the beginning of the experiment, any resistance of the copper wire can readily be reduced to the corresponding temperature on the Centigrade scale.

Results.

After converting the resistances of the copper wire into degrees Centigrade by means of the above formula, the resistances of the amalgam were plotted as ordinates and the temperatures, as abscissas. The exact path of some of the curves may be questionable; yet, since several tests were made for each amalgam, sufficient points were obtained to locate the curves satisfactorily.

[1] This value of the temperature coefficient differs about 1.2 per cent. from .00410, the value determined by Professors Dewar and Fleming.

Upon examining the curves in Figs. 1–4 we find at least two prominent breaks, which indicate a change of state in the substance.

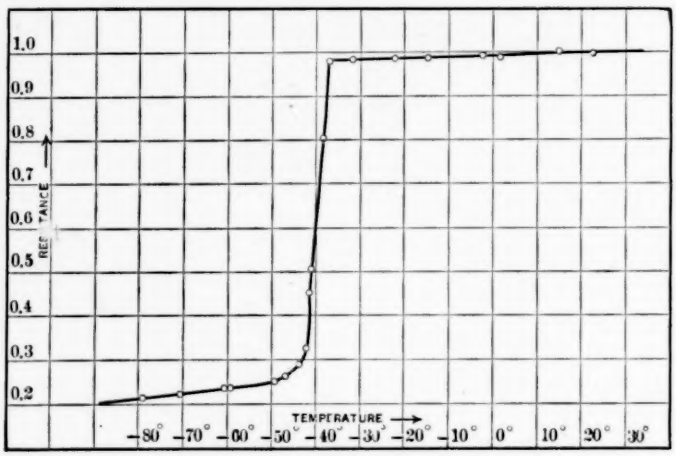

Fig. 1. Lead Amalgam, 4.2%.

The curves from 30°C. to the freezing point are but slightly inclined to the X axis. When the amalgam begins to freeze, how-

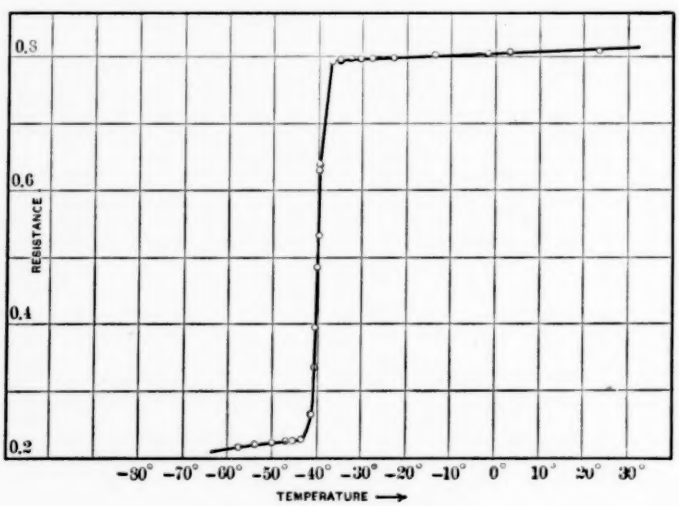

Fig. 2. Lead Amalgam, 7.1%.

ever, the resistance drops off so suddenly that the curve runs at nearly right angles to its former direction. After the process of

freezing is completed, the curve continues nearly parallel again to the first portion. The resistance increased to such an extent upon

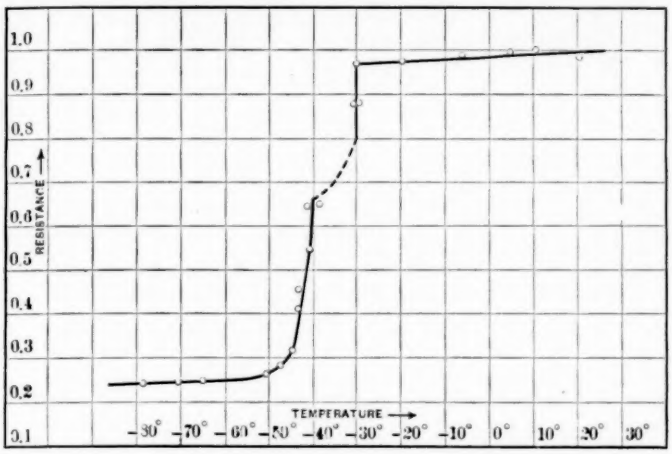

Fig. 3. Lead Amalgam, 11.2%.

freezing that in some cases the resistance of the solid amalgam was only one-fourth that of the liquid amalgam. Although the resistance drops off so suddenly, it was not possible to obtain a curve which

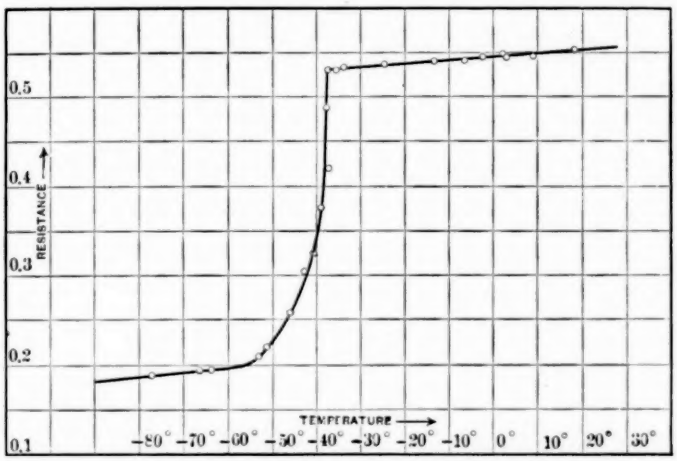

Fig. 4. Lead amalgam, about 25%. Viscid.

indicated that the process of freezing took place at exactly one temperature, as in case of the conversion of water into ice. The

character of the curve suggests what might be termed a freezing point and a melting point; the former the temperature at which the amalgam begins to freeze, and the latter the temperature at which the entire specimen of the amalgam becomes a solid and, consequently, the temperature at which it begins to melt.

MELTING POINT.

The melting point seemed considerably the more difficult to locate. This was undoubtedly due to the fact that the solid amalgam gradually softened, causing the resistance to increase slowly at first and then, upon changing into a liquid, the resistance increased very rapidly until it was entirely converted into a liquid. That the amalgams did soften before melting is shown by the curves in Figs. 1–4, for the junction of the second and third portions of the curves would form a sharp angle as the first and second parts do, if the solid changes at once into a liquid. At present all that can be definitely stated in regard to the melting point is that usually the more lead the amalgam contains, the lower is the melting point. Thus the 25 per cent. amalgam, Fig. 4, began to melt at about $-55°$, while the 4.2 per cent. amalgam, Fig. 1, melted at about $-45°$.

FREEZING POINT.

The freezing point of the amalgam was easily located, since, in every instance, the resistance dropped off very suddenly as the amalgam began to freeze.

Table of Freezing Points.

Composition.	Freezing Points.	Average.
Pure Hg.	−38.8° C.	−38.8° C.
4.2% Pb.	−37.8	−37.7
	−37.6	
7.1% Pb.	−37.1	−37.0
	−36.9	
	−37.0	
11.2% Pb.	−30.2	−30.1
	−30.0	
Viscid Amalgam (25% Pb).	−37.6	−37.65
	−37.7	
Eutectic Alloy.	−40.0	−40.0
	−40.0	
2.4% Solder (Pb and Sm).	−33.1	−33.1

Upon examining the above table we find that, barring the extremes (where the amalgam is viscid and the eutectic[1] alloy), the rise in the freezing point depends upon the amount of lead in solution. Thus the 4.2 per cent. amalgam, Fig. 1, froze at $-37.7°$ and the 11.2 per cent. amalgam, Fig. 3, froze at $-30.1°$.

Non-homogeneity of the Amalgams.

When the curve for the 11.2 per cent. amalgam was plotted, a peculiar break was found in the second portion of the curve. The amalgam plainly began to freeze at $-30.1°$, but suddenly the temperature decreased to about $-40°$. Although the test was repeated with similar results the exact path could not be determined. The curves for the other amalgams was then inspected, and similar breaks, only far less noticeable, were observed in them as is shown in Figs. 1, 2 and 4. This was taken to indicate that the amalgams are not homogeneous, and the second break marks the freezing point of one particular amalgam. Many alloys do possess a second freezing

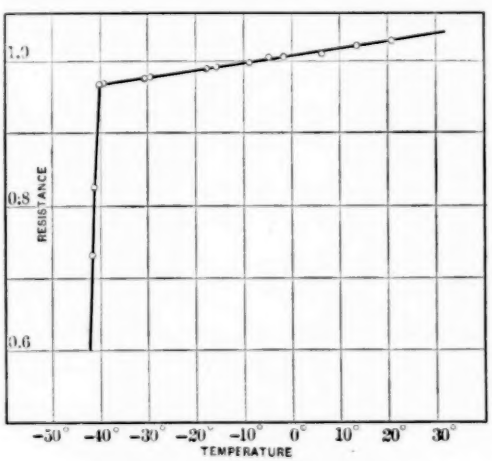

Fig. 5. Lead. Eutetic alloy.

point which corresponds to the freezing point of the eutectic alloy. Hence if the lead amalgams do consist of a mixture, having different freezing points, it was supposed that the one having the lowest

[1] The alloy having the lowest freezing point of any combination of the metals in question.

freezing point could be separated by freezing the larger part of the amalgam and then pouring off the small part, still liquid. Upon treating a dilute amalgam in this manner, the part remaining was found to freeze at — 40° C. This agrees almost exactly with the second break of the amalgams as noted above; thus corroborating the supposition made that the amalgams do possess a second definite freezing point.

VISCID AMALGAM.

That the amalgams are not homogeneous is proven by the fact that whenever an amalgam contained 5 per cent. or more of lead, a thick mass separated out, which, however, could be converted into a pure liquid by trituration or heating. The more lead the amalgam contained the more of this viscid amalgam was formed. As near as could be determined without a chemical analysis, this amalgam contained about 25 per cent. of lead, and proved to be especially interesting. An amalgam was formed containing about 20 per cent. of lead from which the thick mass was

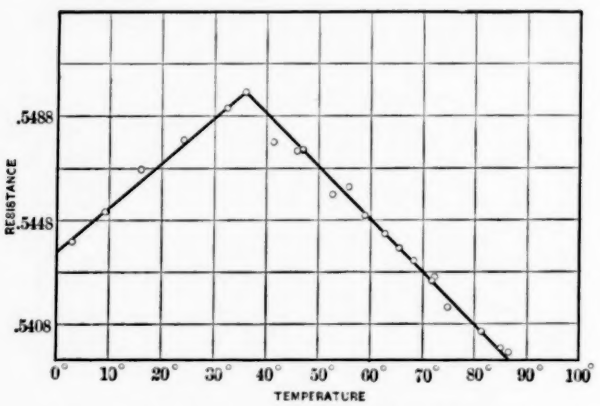

Fig. 6. Lead amalgam, about 25% lead. Viscid.

and carried through a range of temperature from 90° to — 60°. The temperature curve obtained is approximately a straight line from 32° to — 37.7° (see Figs. 4 and 6). At the latter temperature theresistance of the amalgam dropped off very suddenly and it froze like the other amalgams. In the neighborhood of 32° the temperature coefficient became *negative* and remained negative and

approximately constant to 90°. This seems especially remarkable, since the thick mass changed into a definite liquid during this rise in temperature, and from analogy with the other amalgams one would expect it to have a comparatively large temperature coefficient. Furthermore, for no temperature between — 10° and 90°, did its resistance differ more than one and one-half per cent. from that at ordinary temperatures.[1]

Temperature Coefficients of Other Amalgams.

Owing to the fact that the resistance of nearly all the amalgams were at least one per cent. larger at ordinary temperatures, after having been cooled down or warmed up to any considerable extent, but little accurate work could be done in determining the temperature coefficients. The 7.1 per cent. amalgam was especially erratic. Frequently it could be cooled down 20° or more with scarcely a perceptible change in the resistance, but, upon allowing it to warm up, its resistance would increase quite suddenly about one per cent., after which it would again have a very small temperature coefficient. This change of resistance is probably due to a change in state of some portion of the amalgam.

While the temperature coefficients could not be accurately determined, observations were sufficient to show that all the amalgams investigated have a smaller temperature coefficient than pure mercury, and that for those containing a large percentage of lead, it is very small.

Physical Laboratory of Cornell University.

[1] This experiment was repeated several times, with both increasing and decreasing temperatures, and three of the curves approximately coincided. The principal difficulty was to obtain the exact temperature at which the temperature coefficient changed from a positive to a negative value, and, also, the nature of the curve during this change. As the time for this work was limited, and the difficulty could not be easily overcome, since the change of resistance per degree was so slight, the sharp angle at 32°, indicated in Fig. 6, may not be absolutely correct. The general path of the curve, however, is unquestionably correct.

THE WEHNELT ELECTROLYTIC BREAK.

BY W. J. HUMPHREYS.

THE Wehnelt electrolytic break, as is generally known, consists essentially of a small positive and a large negative electrode in an electrolyte of good conductivity. This arrangement, in series with the primary of an induction coil, under proper conditions, makes and breaks the circuit in a manner that often gives better results than can be obtained with any other known device.

The ease with which this break can be constructed and the excellence of its action caused me, as they have many others, first to try it and then to adopt it for most work with induction coils. Naturally, the instrument being new to me, I tried it under a variety of circumstances and, as in certain cases the conditions of my experiments and the resulting phenomena are different from those described by other observers, it seems worth while, owing to the importance of this remarkable break, to publish them.

The currents used were furnished, in nearly all cases, by a storage battery giving any voltage up to 75. A direct 110-volt circuit was also tried, but did not suit the experiments so well.

For the sake of clearness and ease of reference I shall group the observations under several heads.

ELECTRODES.

For negative electrodes I used sheets of lead, copper, amalgamated copper and coils of copper wire all with equal success. In all cases the positive electrode consisted of platinum sealed into the end of a glass tube, and connected to the circuit wire by means of mercury. This electrode was adopted not only because it is so easy to make but also because, if to last, it must be able to resist the action of oxygen even in the form of ozone. The wires used varied from one-fourth to one millimeter in diameter, and from one and a-half to twelve millimeters in length. In one case the end of

the wire was fused to a globular form, in another the wire was looped, both ends being sealed into the glass; in still another the electrode was a piece of sheet platinum sealed across the end of a glass tube, its edges being covered by glass. The usual form, however, was a short straight wire. In some cases the electrode pointed down, in others horizontally, in still others up. In all cases, however, the character of the action was quite the same, though electrodes, with larger surface, demanded larger currents and higher voltage to put them in action. Under the same conditions the larger electrodes produced less frequent breaks and gave discharges of larger volume from the secondary than did smaller electrodes. The distance, within wide limits, between the positive and negative electrodes has but little effect on the general result. The same is true in regard to the position of the positive electrode, provided the gases formed around it can be replaced easily and quickly by the electrolyte.

In making these electrodes I first sealed a bead of blue enamel glass on the wire, and that in turn to a tube of soft German glass. When made in this way they seem to stand the roughest sort of usage without cracking or giving any other kind of trouble.

In some cases at least that part of the platinum which is in the mercury becomes very nicely amalgamated, a phenomenon I had not anticipated nor do I know yet the exact conditions under which it happens.

After considerable use that part of the platinum which is in the electrolyte becomes thickly pitted, giving it, under the microscope, a beautiful frosted appearance. This is due doubtless to an arc discharge, to be described later on, formed between the platinum and electrolyte each time the circuit is being broken.

Electrolytes.

Those electrolytes that conduct best give the best results with the break. They also give the most vigorous action when their concentrations are such as to give the best conductivities at the temperature at which they are used. Thus for 18°C. the best mixture of sulphuric acid and water is about 30 per cent. acid and 70 per cent. water, though the action is still quite good both with more dilute and more concentrated acid.

Hydrochloric acid and nitric acid are both quite as good, for a time at least, as sulphuric, probably even a little better, since, according to Kohlrausch, they are slightly better conductors.

Of the various salts tried ammonium chloride is one of the most interesting in its action. Under the same conditions it does not give as long nor so heavy sparks as does sulphuric, nitric or hydrochloric acid; still the action is very good and the rapidity of the break is much greater, giving under suitable conditions a note both clear and shrill.

The case of melted ammonium nitrate is also interesting, showing

ELECTROLYTES TESTED.

Name.	Action.	Remarks.
Sulphuric acid	Excellent	Good conductor
Hydrochloric acid	Excellent	Good conductor
Nitric acid	Excellent	Good conductor
Boric acid	None	Very poor conductor
Oxalic acid	None	Very poor conductor
Hydrobromic acid	Slight	Weak solution used
Phosphoric acid	Fair	Moderate conductor
Sulphurous acid	None	Very poor conductor
Ammonium sulphate	Slight	Rapid break
Copper sulphate	None	Very poor conductor
Sodium sulphate	Slight	Poor conductor
Acid sodium sulphate	Slight	Poor conductor
Ammonium chloride	Well	Very rapid break
Calcium chloride	Slight	Rapid break
Lithium chloride	Slight	Poor conductor
Sodium chloride	Fair	Moderate conductor
Potassium chloride	Fair	Rapid break
Strontium chloride	Slight	Poor conductor
Zinc chloride	Fair	Moderate conductor
Ammonium nitrate	Fair	Rapid break
Ammonium nitrate, fused	Slight	Action irregular
Sodium nitrate	Fair	Rapid break
Bromine water	None	Very poor conductor
Potassium bromide	Slight	Poor conductor
Sodium bromide	Slight	Poor conductor
Sodium carbonate	Slight	Rapid break
Acid sodium carbonate	Slight	Rapid break
Sodium bichromate	Fair	Moderate conductor
Caustic soda	Fair	Ropid break
Potassium iodide	Fair	Moderate conductor

as it does that the break may act, though irregularly and feebly, at a relatively high temperature and without the presence of water.

The above table contains a list of the substances tested. Of course this could have been greatly extended, but it did not seem necessary.

To Prevent Acid Spray.

Dilute sulphuric acid seems to be the best electrolyte for general use with the break, and while the acid does not evaporate or give off, during the action of the break, any objectionable gases, still if an open vessel is used, the bursting of the bubbles soon fills the air with acid spray which is both disagreeable and injurious to apparatus. Of course, several methods may be devised to prevent this, but I have found a covering of paraffin oil to be perfectly satisfactory. The electrodes may be dipped back and forth through the oil without its adhering to them sufficiently to prevent their prompt action when the circuit is closed. This oil covering has the further advantage of preventing any change in bulk of the electrolyte, due to evaporation or absorption of water, while the break is not in use.

Glow About Anode.

During the action of the break there is a more or less brilliant glow about the anode. When there is no glow the current is not interrupted. The converse of this, however, when there is no break there is no glow, is not true, for during the high resistance stage, to be described below, when there is no breaking of the circuit, there is a feeble but continuous glow on a part of the anode, stationary at points and apparently coming and going along rough places in a manner that reminds one of brush discharges.

On examining the glow with a revolving mirror, when the break was running nicely, it was found to be intermittent, the light appearing at uniformly spaced intervals, with, so far as I could tell, total absence of light between them. Rapid revolving seemed only to increase the spaces between the flashes of light and not to stretch out the light at all appreciably.

The spectrum of this light contains, certainly, lines of hydrogen, oxygen and other things, owing to the nature of the electrolyte.

Those electrolytes containing sodium give a brilliant yellow glow, while calcium chloride gives a brilliant red glow and a beautiful spectrum of calcium. Similar phenomena are true of the potassium and lithium salts. The pinkish glow in dilute sulphuric acid is due mainly to the brilliant red line of hydrogen.

The fact that these glows give line spectra of hydrogen and oxygen is well-nigh positive proof that the light is due to an electric discharge through these gases or compounds of them surrounding the electrode, since the only certainly known method of obtaining line spectra from small amounts of hydrogen and oxygen is by means of passing an electric discharge through them.

EFFECT OF MAGNETIC FIELD.

On placing the break in a strong magnetic field so that the lines of force were at right angles to the current, it was found that its action was greatly disturbed. When the voltage was just high enough to run it nicely under ordinary circumstances, it would not act at all in a magnetic field; when, however, the voltage was high it would act, but very irregularly; the glow seemed to be blown out almost as soon as formed and then to begin again very soon, once more to be blown out and so on indefinitely.

EFFECT OF CHANGE IN HYDROSTATIC PRESSURE.

It does not take a very great change in hydrostatic pressure to produce a noticeable change in the pitch of the note given by the break and in the character of the spark from an induction coil connected with it. An increase in the pressure lowers the frequency of the discharge and produces heavier sparks, while at very low pressures the action of the break is quite feeble.

GASES GENERATED.

The kind and quantity of the gases generated by the positive pole of the Wehnelt break are different from those obtained during the process of quiet electrolysis, at least this is the case with the substances examined, sulphuric, nitric and hydrochloric acids and ammonium chloride. The proportions vary with the size of the electrode, voltage of the current, and other conditions. The nega-

tive pole gives off hydrogen alone. When the break is running best in a solution of sulphuric acid the volume of the gas from the positive pole is very nearly equal to that from the negative, instead of being only about half as great as it is in the case of quiet electrolysis. This gas consists of a mixture of hydrogen and oxygen. After exploding it the remaining gas is oxygen alone, but not nearly enough to account for the hydrogen from the negative pole on the assumption that the gases come from the decomposition of the water only. I used long eudiometers made from the same glass tube of about two centimeters internal diameter and a typical case gave the following result:

Before explosion, { Length of gas column over negative pole 28.5 cm.
" " " " " positive " 22.0 "

After explosion, { Length of gas column over negative pole 28.5 cm.
" " " " " positive " 7 "

A number of sparks were passed through the gas in each eudiometer, but the gas over the negative pole, being hydrogen alone, did not change in volume, while that over the positive pole exploded quite vigorously. The mixture of hydrogen and oxygen can be accounted for by the decomposition of the water by the arc discharge that forms the flashes of light about the positive pole. More or less ozone and persulphuric acid are also to be expected about the positive pole, but whether these can in any way fully account for the relatively small volume of oxygen left after the explosion is an interesting question which at present I cannot answer.

I also found the gases from the positive pole in nitric acid to explode, but not very violently. The residue was oxygen. In the case of hydrochloric acid the explosion was quite violent, probably between hydrogen and chlorine, at any rate the remaining gas consisted largely or entirely of oxygen.

I did not risk collecting much gas from ammonium chloride, but the small amount produced a violent explosion that jerked the eudiometer from its support and broke it. Probably in this case not only hydrogen, chlorine and oxygen were present, but also a small amount of nytrogen trichloride, one of the most violent explosives known.

PLACE OF CLOSING CIRCUIT.

It has been affirmed and denied that the place of closing the circuit has anything to do with the action of the break. My own experience convinces me that with a given electrode, external resistance, which should be low, etc., it depends upon the voltage. If the voltage is low, just enough to run the break properly, then it starts at once no matter where the circuit is closed. If it is closed by dipping the electrode into the acid it starts up as soon as it touches the liquid, though the action, so long as the electrode is kept at the surface is somewhat irregular and the liquid is spattered about. On pushing the electrode below the surface the action goes on nicely. If however the voltage is high then the electrode must be put into the acid first and the circuit closed on the outside. If closed by dipping the electrode into the acid the high resistance state, to be described below, is formed at once, and this too no matter how quickly or slowly the electrode is immersed. With intermediate voltages the action is uncertain. Sometimes the breaking begins at once, at others the high resistance state is formed which, if left alone, may or may not give way to breaking.

VOLTAGE REQUIRED.

While working with a small electrode I found that the current rose with the voltage to a maximum, the value of which depended, among other things upon the self induction of the circuit, and then decreased with further increase of the voltage. The break however did not appear to run regularly at the higher voltages, as it gave a somewhat harsh or ragged sound. The particular electrode used, with a surface of only four or five square millimeters gave a maximum current in sulphuric acid with about 50 volts.

TYPES OF ACTION OF ELECTRODES.

The positive electrode has three stable conditions of activity that differ very greatly from each other. I shall call these for convenience the high resistance stage, which allows a very small current to flow, the stage of quiet electrolysis which carries a much larger current, and finally the stage of regular breaking which gives the largest current of all. These do not merge gradually the one into

another, but change abruptly. The high resistance stage is characterised by minute but steady glows on points and along rough edges, a small current, considerable heating, and a peculiar frying noise. The stage of quiet electrolysis by absence of light and noise, together with a relatively large current. The regular breaking stage by a clear-cut note of constant pitch, a bright but intermittent glow and a large average current.

Resistance in Circuit.

An adjustable resistance of considerable range in series with the break gives some interesting results. When the resistance is large the current produces only quiet electrolysis. On decreasing the resistance the electrolysis increases till a certain current, depending largely upon the size of the electrode, but not upon the voltage, is reached when irregular breaking and a decreased average but variable current is obtained. On still further decreasing the resistance the break usually becomes steady and the current quite large. Sometimes, however, instead of becoming steady the break gives way to the high resistance stage which remains comparatively unaltered through a wide change in the external resistance. Breaking the circuit and connecting it again will now start the break to running regularly if the resistance is small, or begin quiet electrolysis if the resistance is large. On sufficiently increasing the external resistance the high resistance stage disappears abruptly with a peculiar click, and is followed by quiet electrolysis.

When the voltage is comparatively low the high resistance stage often ceases of itself with a sudden outburst of breaking, this in turn may soon be followed by a renewal of the high resistance stage and so on indefinitely but irregularly. In no case, however, have I seen the full breaking stage give way to quiet electrolysis nor the reverse.

Self-induction in Circuit.

An increase in the self-induction of the circuit lowers the frequency of the break. With very small self-induction the break can be obtained only with correspondingly small anodes. A decrease in the self-induction also causes an increase in the average current. I tried, with two coils, and with different electrodes and various voltages

from 35 to 75 the effect of short-circuiting the primary, and found in every case, where the break continued to run with a clear note, that its frequency and the average amperage both increased when the coil was cut out. This increase of current is just the reverse of that described by H. Pellat, C. R., 12, CXXVIII. With relatively large electrodes, however, the break often did not continue to run smoothly when the coil was cut out, and occasionally changed in a little while from irregular breaking to the high resistance stage. In these cases, that is when on cutting out the coil the break became irregular, the current at the same time became exceedingly variable and its average value decreased.

FORMATION OF THE GAS.

When the break is running the bubbles of gas are hurled from it with considerable velocity. This I found most marked with the anode of sheet platinum. When sulphuric, nitric or hydrochloric acid is used the bubbles are relatively large, while ammonium chloride, sodium nitrate and others, especially those that give high frequency, produce some bubbles of fair size together with vast numbers of exceedingly minute ones that give the liquid a milky appearance.

SHUNT TO BREAK.

A shunt to the break when its resistance is large carries a greater current when the break is running than it does even when it is the only resistance in the circuit. This is very nicely shown with an incandescent lamp in the shunt. If the resistance of the shunt is gradually decreased the break begins to act irregularly, and soon ceases entirely.

ELECTRODES IN SERIES.

When a large and a small electrode are connected in series, and the voltage is suitable, the large one gives quiet electrolysis while the small one produces the breaking quite the same as when it alone is in the circuit, except in so far as its frequency is decreased by the resistance of the large electrode. When both electrodes are approximately the same size both may break the circuit, but the action is irregular and does not give a clear note.

Uses.

It is not my purpose to discuss the various uses of the Wehnelt break, which seem to be nearly all those of any other, but simply to mention one or two things I have come across in using it practically. So far I have not obtained very satisfactory results with it in connection with a twelve-inch coil wound for a direct 110-volt circuit, nor have I examined the conditions sufficiently to know just what the trouble is.

In using the break on an ordinary Ruhmkorff coil for a large X-ray tube, I obtain best results with a break of moderate frequency, about three hundred per second. Higher frequency causes the tube to light up throughout, nor is this obviated by the introduction of a spark gap. With a suitable sized electrode, however, the action is most satisfactory for both fluoroscopic and radiographic work. Thus with an exposure of only two seconds I secured a fully exposed and excellent radiograph of a man's hand, while with the fluoroscope it is perfectly easy to see through any part of the body of an adult, the light meanwhile being quite free from all flicker.

Action of Break.

I do not claim the following explanation to be either complete or wholly free from error; it is only that which my experiments have suggested to me.

With moderately high voltage the current grows quickly though gradually on account of the self-induction, till the electrode is completely sheathed by a layer of gas—chiefly or entirely oxygen. This gas abruptly breaks the circuit and the self-induction sends an electrical discharge across it, giving rise to the light and at the same time decomposing some of the liquid, giving among other things oxygen and hydrogen. The sudden freeing of these gases and the heat of the discharge together produce an explosive effect, as shown by the noise and the violence with which the bubbles are thrown off. Probably no part of the hydrogen and oxygen set free is again recombined. The flash seems due to a single discharge, certainly there can be no oscillations, and as some of the liquid is undoubtedly decomposed, as shown by the gases collected, it does not seem clear how the same discharge can also cause them to recombine;

at any rate a part of the gas remains decomposed, and it seems highly probable that this would not be so if a single discharge could decompose water into its elements and at the same time trail after itself a recombination of them.

The explosion over, the liquid drops back onto the electrode, cleared by the discharge of any polarization, and the process renews itself.

According to this, disturbance from a magnetic field is to be expected, so too are the effects of changes in hydrostatic pressure, the actions of large and small electrodes, or high and low voltages, of changes in resistance, self-induction, and other things as already described.

I am very sorry that I cannot, owing to want of apparatus, examine the break with a rapid curve tracer, such as the one described by Mr. H. J. Hotchkiss in the PHYSICAL REVIEW for March, 1899.

I venture to say, however, that such a trace will show the current to rise gradually from zero to a certain maximum and then to drop very nearly abruptly to zero again, and so on indefinitely. At break of current the voltage will probably rise quite high, to an extent dependent, of course, among other things, upon the self-induction of the coil. At make of current the voltage, probably differing but little by this time from that of the battery, may fall slightly and then continue very nearly constant till the next break.

I have not attempted to give the bibliography of the break, partly because my work has been independent of other observers, but chiefly because it is too soon, owing to the large number of short articles appearing on it, to make the bibliography at all complete or serviceable.

ROUSS PHYSICAL LABORATORY, UNIVERSITY OF VIRGINIA, April 14, 1899.

THE HYDROLYSIS OF STANNIC CHLORIDE.[1]

By William Foster, Jr.

MANY compounds when in aqueous solution are acted upon by the water, some of the atoms or radicals of the compounds being replaced by the hydroxyl (OH) group. This familiar phenomenon is termed *hydrolysis*. Such bodies as stannic chloride and ferric chloride belong to this class of compounds. The rate at which a body undergoes hydrolysis is largely regulated by the amount of water present in proportion to the compound, a large amount of water facilitating hydrolysis. Stannic chloride is one of the most instructive examples of this class of compounds, for the rate at which it suffers hydrolysis in solution of medium concentration is so gradual that the observer has ample time to determine the condition of the solution as the reaction progresses, and at the same time final equilibrium is reached without having to wait too long.

In determining the resistance of a freshly-prepared solution of half-normal $SnCl_4$, I observed that the bridge-reading was not constant, but that it changed in such a manner as to indicate that the conductivity of the solution *increased*. As the change in the conductivity was so gradual, it at once suggested the idea of measuring the conductivity of a solution from time to time until it should become constant. A number of such measurements have thus been made.

It will be remembered that Loomis[2] found very large and surprising values for the molecular depression of the freezing-points of aqueous solutions of this salt. Thus while the maximum values found by him in other salts did not exceed 5.5, the value for $SnCl_4$ was found to be 12.61 for $m = 0.04$ ($m = 0.01$ according to Loomis).

[1] Part II. of thesis presented to the faculty of Princeton University for the degree of Doctor of Philosophy.

[2] Phys. Rev., Vol. IV., No. 22, 1897, pp. 278 and 294.

The *complete* dissociation of this salt as such could not account for this depression, and the present work was undertaken at the suggestion of Professor Loomis with the hope of finding some explanation of the phenomenon from the behavior of the compound as an electrolyte.

HISTORICAL.

Stannic chloride was known to the ancient chemists. It was mentioned by Libavius as far back as 1605, and it was early termed *Spiritus Fumans Libavii.* It has been known for some time that it is not stable in dilute aqueous solutions, but that it undergoes hydrolysis, forming a hydrate of tin.

It has also been thought for some time that tin forms at least two hydroxides. These are sometimes termed stannic and metastannic acid, or α- and β-stannic acids, respectively.

Berzelius, early in the present century, observed the difference between these bodies. He thought that the stannic acid was obtained by treating $SnCl_4$ with alkalies; and the metastannic acid, by treating tin with nitric acid.

The following are some of the very conflicting opinions held regarding the properties and composition of these bodies:

Stannic acid is transformed into metastannic acid by desiccation. It *cannot* be isolated in the dry state.[1] (Berzelius, Graham.) Stannic acid *can* be isolated without alteration. Its composition is the same as metastannic acid. (Neumann, Schiff, Lorenz.)[2]

The composition of metastannic acid dried in a vacuum is $(SnO_2)_5 . 5H_2O$. (Fremy.)

The metastannates do not exist: they are stannates with excess of stannic acid. (Berzelius.) There exist between these bodies two or more acids. (Leó Vignon.)

There are two isomeric stannic hydrates, each of which behaves as an acid, yielding corresponding salts.

Both acids exist in all degrees of hydration between H_2SnO_3 and H_4SnO_4; no satisfactory explanation of their difference has been given. If $SnCl_4$ be treated with such compounds as NH_4NO_3 and

[1] R. Engel, Compt. Rend., 125, 651; 1897.
[2] Zeit. Anorg. Chem., 9, 376; 1895.

Na_2SO_4; it yields H_4SnO_4 when dried in the air; and H_2SnO_3 when dried over H_2SO_4. Stannic hydrate is slightly soluble in water, and dissolves readily in dilute mineral acids. (Roscoe.)[1]

Acid solutions of SnO_2 treated with alkalies, precipitate $Sn(OH)_4$ (stannic hydrate), also known as stannic acid. It is a colloidal substance having several modifications which are identical in composition. The various hydroxides have also a different appearance and behave differently with reagents. There is a difference between ordinary stannic acid and metastannic acid. Stannic acid is precipitated from $SnCl_4$ by treating it with alkalies, and metastannic acid is obtained by treating tin with HNO_3. Metastannic acid is insoluble in water in the presence of HCl. (Mendeleeff.)[2]

The cause of difference is due to polymerization.

The ordinary acid corresponds to SnO_2; and the metastannic acid, to Sn_5O_{10}. (Fremy.)

The following opinions are entertained in regard to the change which $SnCl_4$ suffers in aqueous solution: Dilute HCl, especially when boiling, changes the ordinary hydrate which is first formed into metastannic acid. On this depends the formation of a white precipitate, stannic hydrate, in dilute aqueous solutions. (Mendeleeff.) When solutions of stannic acid in HCl (identical with solution obtained by the action of H_2O on $SnCl_4$) are allowed to stand, the stannic acid slowly undergoes conversion into metastannic acid, which usually separates out as an opalescent precipitate. (Roscoe.)

The dilute solution of $SnCl_4$ gradually decomposes, yielding HCl and metastannic acid. (Watts' Dict. of Chem.)

The solution of $SnCl_4$ diluted to a certain point yields *stannic hydrate* as well as metastannic acid. (Casselman.)

Stannic chloride boiled in water yields H_2SnO_3 and HCl, — $SnCl_4 + 3H_2O = H_2SnO_3 + 4HCl$.

Probably the following reaction takes place first:

$$SnCl_4 + 4H_2O = Sn(OH)_4 + 4HCl.$$

$Sn(OH)_4$ loses a molecule of H_2O and forms H_2SnO_3, stannic acid. (Remsen.)

[1] Treatise on Chem., Vol. II., 1897.
[2] Treatise on Chem., Vol. II., London, 1897.

APPARATUS.

The apparatus employed in measuring the conductivity of solutions of $SnCl_4$ was the same as that described in Part I. of this thesis, with the addition of a thermostat.[1] The measurements in the thermostat were conducted at 28° C. It was easy to regulate the thermostat so that the temperature varied only a small fraction of a degree (usually much less than $\frac{1}{10}$) for hours at a time. Other measurements were made at 18°.

THE PREPARATION OF THE COMPOUND.[2]

To prepare $SnCl_4$, c. p. tin was melted in a retort, and a strong, dry stream of chlorine was conducted into it, whereby $SnCl_4$ was formed. It is a strongly-fuming liquid; consequently a long condenser was connected with the retort, and the salt condensed in a pair of Woulf bottles surrounded by an ice bath. The liquid was transferred to a fractionation flask and some tin foil added to unite with the dissolved Cl. The $SnCl_4$ was distilled, treated with tin foil again, and the distillation repeated until the liquid became colorless and had a constant boiling-point.

The liquid was preserved in a well-stoppered flask to prevent access of aqueous vapor. The normal solution was prepared by first making up a solution of specific gravity 1.0927. This was analyzed, the Sn being determined as SnO_2 by precipitation as stannic hydrate by means of a strong solution of NH_4NO_3, with the following results:

I.	5 c.c. of the solution gave	0.3551	g.	SnO_2
II.	" " " "	0.3561	"	"
	mean value	0.3556		

This corresponds to 123.16 grams of $SnCl_4$ per liter. Accordingly, 288.23 grams of this solution were diluted to 500 c.c.

10 c.c. of this gave 0.3752 grm. SnO_2, which corresponds to 65.07 grms. of $SnCl_4$ per liter. 64.975 grams are required for a normal solution. This indicated that the solution was 0.15% too

[1] Ostwald, Physiko-Chem. Messungen, Leipzig; 1893, p. 70.
[2] Chemische Präparatenkunde, Bender and Erdmann, Stuttgart.

strong, so it was diluted to normal strength. This solution was employed in preparing most of the dilute ones. For a few of the more concentrated solutions, the ordinary c. p. salt was employed. The strength of the solutions, other than those prepared by direct

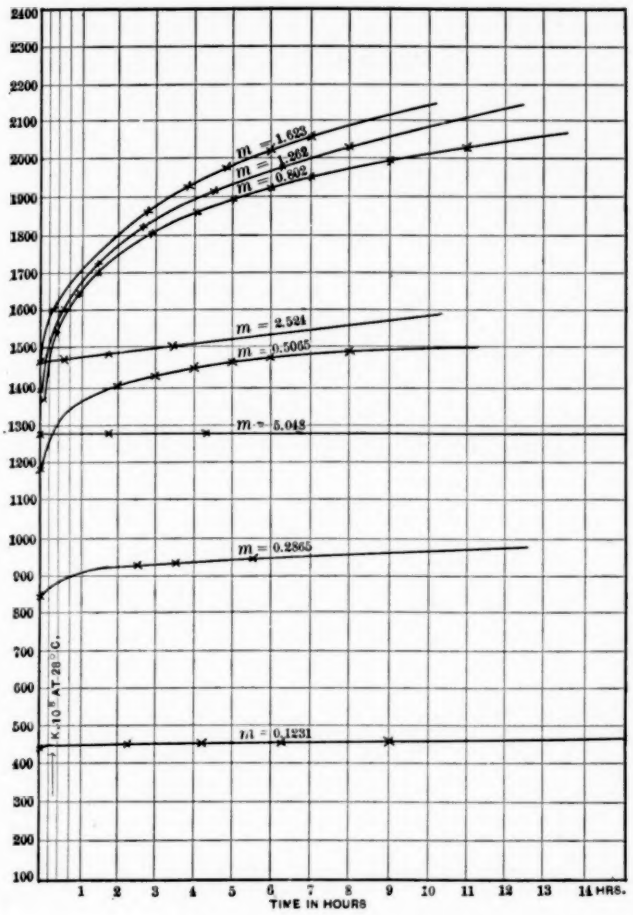

Fig. 1.
Curves for $SnCl_4$.

dilution from a solution of known strength, was determined by chemical analysis in some cases; and in others, by comparison of their sp. gr. with the sp. gr. of the solutions of known strength.

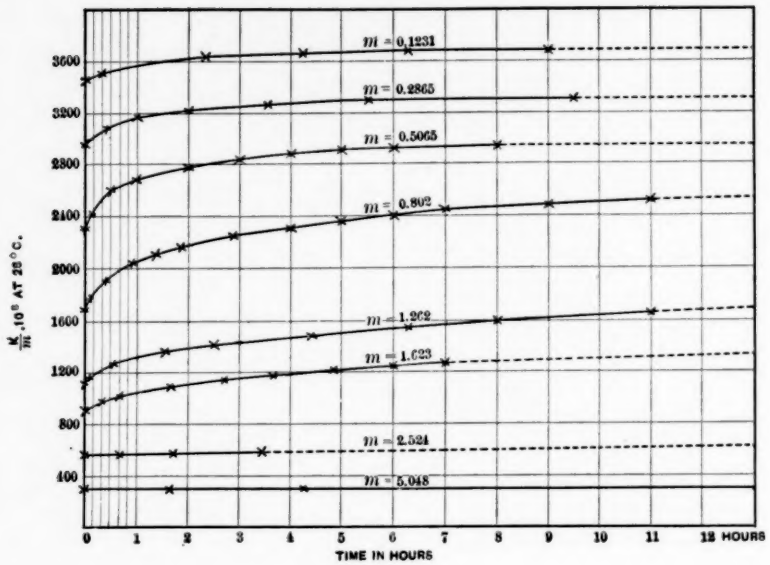

Fig. 2.

Curves for $SnCl_4$.

THE MEASUREMENTS.

The Normal Solution.

The specific gravity of the normal solution of $SnCl_4$ was found to be 1.0496 ($\frac{18°}{4°}$). The solution was prepared from the pure liquid salt on November 12, and the values of $\frac{K}{m}$ (equivalent-conductivity) at 18° are given below:

	$\frac{K}{m} \cdot 10^8$ at 18°C.
November 14,	1805
" 18,	2040
December 23,	2265
February 21,	2340

This solution remained *clear*, and stood in a room whose temperature averaged about 15°. It is thus seen that the normal solution changes more rapidly during the first few days after its preparation, and that it would be months in coming to its maximum con-

ductivity. Solutions from m=0.0001 to m=0.01 were prepared from the normal solution as in the first part of this work.[1] Two series of measurements were carried out. The results are given below. The concentration m in *gram-equivalents* is given in the first column; the specific conductivity at 18° (Hg at 0°=1) is given in column 2; and the equivalent-conductivity $\frac{K}{m}$ is found in column 3.

	First Series.		Second Series	
m	$K_{18} \cdot 10^{10}$	$\frac{K}{m} \cdot 10^{8}$	$K_{18} \cdot 10^{10}$	$\frac{K}{m} \cdot 10^{8}$
Water.	(1.83)	——	(2.10)	——
0.0001017	37.06	3460	32.52	2990
0.0002032	71.08	3400	67.35	3210
0.0006077	205.07	3350	204.61	3320
0.001009	344.2	3390	342.40	3370
0.002015	683.7	3390	685.70	3390
0.006024	2010.5	3330	2010.5	3330
0.01000	3300.0	3300	3313.0	3310

The measurements of the first series were made as rapidly as possible, while more time was used in obtaining the second series. It is seen, then, in the *extremely dilute* solutions that the equivalent-conductivity *decreases*. The same phenomenon is characteristic of acids and bases.

When m = about 0.001, the value of the two series come together, however, and solutions of such strength change very little with time. To ascertain just how much a solution in which m = 0.001 does change, or how much time it requires to come to final equilibrium, one was prepared directly from the normal solution, with the following result:

m = 0.001	$\frac{K}{m} \cdot 10^{8}$ at 18°
Feb. 6, 11 a. m.	3100
" " 2:30 p. m.	3440
" " 5 "	3440

It is thus seen that this solution reaches its maximum conductivity within two or three hours. It changes very rapidly at first.

[1] Physical Review, May-June, 1899.

For $m = 0.01$, the freshly-prepared solution gave $\frac{K}{m}.10^8 = 3300$, and this soon reached a maximum value of 3475. Some interesting conclusions may be drawn from the facts now before us, namely:

1. The final conductivities of the solutions of $SnCl_4$ $m = 0.01$ and 0.001 are almost identical with those of HCl of the same concentrations.

m	$SnCl_4$	HCl.
0.001	3440	3520 $\left.\right\}$ $\frac{K}{m}.10^8$
0.01	3475	3470 $\left.\right\}$

For $m = 0.01$, these values are practically identical.

2. For the most dilute solutions of $SnCl_4$, the values of $\frac{K}{m}$ become smaller. The same is true of HCl in dilute solutions.

3. The *dilute* solutions of $SnCl_4$ soon come to equilibrium, that is, the hydrolysis of the salt is soon completed.

It is worthy of note that these dilute solutions yield a white, amorphous precipitate. It is a well-established fact that many chlorides undergo hydrolysis to a greater or less extent, generating at the same time HCl; and it has been known for some time that a large quantity of water, especially when heated, causes an aqueous solution of $SnCl_4$ to precipitate a compound variously termed "stannic hydrate," "stannic acid" and "metastannic acid."

From the data and facts given above, it would seem that the stannic compound formed by the action of the water, even before the separation is complete, is not dissociated to any considerable degree; but that the conductivity of the solution depends almost entirely upon the HCl that is generated.

The following reaction perhaps takes place:

$$Sn\begin{matrix}Cl\\Cl\\Cl\\Cl\end{matrix} + \begin{matrix}HOH\\HOH\\HOH\\HOH\end{matrix} = Sn\begin{matrix}OH\\OH\\OH\\OH\end{matrix} + 4HCl$$

(Stannic Hydroxide.)

$$Sn\begin{matrix}OH\\OH\\OH\\OH\end{matrix} = H_2SnO_3 + H_2O$$
(Stannic Acid.)

$5H_2SnO_3 = H_{10}Sn_5O_{15}$ (insoluble metastannic acid).

It is here assumed that the $SnCl_4$ first decomposes, forming stannic hydroxide, and generating four molecules of HCl. The $Sn(OH)_4$ then loses a molecule of water, forming stannic acid, and then the H_2SnO_3 molecule condenses to form $H_{10}Sn_5O_{15}$ (metastannic acid).

This is an insoluble, colloidal body which gradually settles down as a white precipitate.

100 c.c. of the $\frac{n}{100}$ $SnCl_4$ solution (*i. e.*, the clear supernatent liquid) was found to be in exact balance with 10 c.c. of $\frac{n}{10}$ NaOH, thus showing that an equivalent amount of HCl was in fact generated.

Measurements were now made on the $\frac{n}{10}$ solution of $SnCl_4$, with the following results :

	$\frac{K}{m} \cdot 10^5$
Feb. 6, 9:30 a. m.	3125
" " 5:30 p. m.	3154
" 7, 2:00 "	3159
" 21,	3218

The last value remained constant from this time. The value of $\frac{n}{10}$ HCl is 3290.

The $\frac{n}{10}$ $SnCl_4$ (the clear supernatent liquid) was balanced against $\frac{n}{10}$ NaOH, and was found to be 1.6% weak.

Measurements were next made on a number of solutions at 28° with results as follows :

SOLUTION NO. I. $m = 1.623$.

Some of the liquid $SnCl_4$ (about 10 c.c.) was quickly added to about 200 c.c. H_2O. The temperature was quickly brought to 28°, $SnCl_4$ and the resistance of the solution determined without delay. Time of bringing liquid $SnCl_4$ and H_2O together, 12 m.

Time.	Interval in min.	K 10⁸ at 28°	$\frac{K}{m}$ 10⁸
Jan. 11, 12:05 p. m.	0	1485	915
12:10 "	5	1532	944
12:25 "	20	1608	991
1:45 "	100	1757	1083
2:45 "	160	1854	1142
3:45 "	220	1921	1183
5:00 "	295	1981	1221
6:05 "	360	2018	1243
7:05 "	420	2049	1262
Jan. 30.	19 days	2791	1719

II. $m = 0.802$.

Time of bringing $SnCl_4$ and H_2O together, 10.31 *a. m.*

Time.	Interval in Min.	K. 10⁸ at 28°	$\frac{K}{m}$. 10⁸
Jan. 13. 10:35 a. m.	0	1377	1717
10:40 "	5	1440	1796
11:00 "	25	1559	1944
11:30 "	55	1646	2052
12:01 p. m.	86	1706	2127
12:31 "	116	1748	2179
1:31 "	176	1806	2252
2:35 "	240	1857	2315
3:35 "	300	1892	2359
4:35 "	360	1922	2396
5:35 "	420	1948	2429
7:35 "	540	1989	2480
9:35 "	660	2021	2520
Jan. 30	17 days.	2251	2807
Feb. 21	39 days.	2293	2860

2860 at 28° = 2460 at 18°.

III. $m = 0.5065$.

$SnCl_4$ and H_2O came together at 1:50 p. m.

Time.	Interval in min.	$K \cdot 10^8$ at 28°	$\frac{K}{m} \cdot 10^8$
Jan. 18. 1:45 p. m.	0	1183	2335
2:01 "	7	1246	2460
2:24 "	30	1321	2608
2:54 "	60	1362	2689
2:54 "	120	1405	2773
4:54 "	180	1434	2831
5:54 "	240	1451	2878
6:54 "	300	1466	2894
7:54 "	360	1475	2912
9:54 "	480	1488	2937
Jan. 19	1 day	1507	2975
" 30	12 days	1542	3044
Feb. 21	34 days	1562	3084

3084 at 28° = 2660 at 18°.

IV. $m = 0.2865$.

$SnCl_4$ and H_2O came together at 8:59 a. m.

Time.	Interval in min.	$K \cdot 10^8$ at 28°	$\frac{K}{m} \cdot 10^8$
Jan. 17. 9:03 a. m.	0	841	2935
9:07 "	4	857	2957
9:30 "	27	887	3096
10:03 "	60	906	3162
11:03 "	120	921	3215
12:33 p. m.	210	930	3246
2:33 "	330	940	3281
6:30 "	567	946	3302
Jan. 30.	13 days.	957	3340

This solution on standing gave a white precipitate. Nos. I., II. and III. remained *perfectly clear*. The value of m in every case was determined at 15° C.

Four series of measurements were next made, starting with a very concentrated solution ($m = 5.048$). The c. p. $SnCl_4$ (crystalline) of Eimer and Amend was employed. It was analyzed at 15° C.

These solutions will be designated as A, B, C and D.

Solution A. $m = 5.048$.

Time.	Interval in min. min.	$K \cdot 10^3$ at 28°	$\frac{K}{m} \cdot 10^3$
Jan. 14. 9:50 a. m.	0	1272	252
11:32 "	102	1274	252
4:33 p. m.	260	1272	252
Jan. 30	16 days.	1281	256

252 at 28° = 207 at 18°.

B. $m = 2.524$.

Time.	min.	$K \cdot 10^3$ at 28°	$\frac{K}{m} \cdot 10^3$
Jan. 15. 4:05 p. m.	0	1461	579
4:45 "	40	1468	582
5:45 "	100	1479	586
7:30 "	205	1501	594

C. $m = 1.262$.

Time.	min.	$K \cdot 10^3$ at 28°	$\frac{K}{m} \cdot 10^3$
Jan. 16. 9:29 a. m.	0	1409	1116
9:33 "	4	1458	1155
10:00	31	1598	1266
11:00 "	91	1727	1369
12:00 m.	151	1815	1438
2:00 p. m.	271	1913	1516
3:45 "	376	1971	1562
5:30 "	481	2025	1605
8:30 "	661	2103	1666

D. $m = 0.1231$.

Time.	Min.	$K \cdot 10^3$ at 28°	$\frac{K}{m} \cdot 10^3$
Jan. 19. 10 a m.	0	426	3461
10:20 "	20	435	3534
12:20 p. m.	140	446	3623
2:20 "	260	450	3655, Sol. opalescent
4:20 "	380	451	3664, Ppt. forming
7.00 "	540	453	3680
Jan. 30.	11 days.	454	3688 Ppt. all settled down.

Graphic Representation of the Results.

Fig. 1 shows the change, with time, in specific-conductivity at 28° C. (Hg at 0 = 1.)

The ordinates represent the specific-conductivity, and the abscissas represent the time in hours; m, as before, represents the *gram-equivalent* concentration.

In Fig. 2 the equivalent-conductivity $\left(\frac{K}{m}\right)$ is represented by ordinates and the abscissas represent the time in hours.

The solution $m = 1.623$, as shown in Fig. 1, *conducts better than any other solution studied, although m ranges from 0.1231 to 5.048.*

Fig. 2 shows (1) the familiar fact, that the equivalent-conductivity is always greater as the dilution is increased; (2) that for solutions from $m = 2.524$ to 0.1231, the equivalent-conductivity increases with time, soon reaching a maximum value in the more dilute solutions. It is also true that the rate of the increase in the equivalent-conductivity is more rapid and pronounced in proportion as the solution is diluted, but the curves for the more dilute solutions do not show this from the fact that most of the salt suffers hydrolysis before the first measurement can be made.

In suming up the work, the following facts and inferences may be enunciated:

(1) The dilute solutions of $SnCl_4$ are hydrolyzed more rapidly than those of medium concentration, while the very concentrated solutions come to equilibrium at once.

(2) The extent to which hydrolysis takes place is no doubt regulated by the law of mass action as set forth by Guldberg and Waage, and we are dealing with a state of chemical equilibrium or balanced action which may be represented thus:

$SnCl_4 + 4HOH \geq Sn(OH)_4 + 4HCl$. One cannot measure the extent to which hydrolysis takes place, however, by simply determining the electrical conductivity of the solution, for the problem is a complicated one. The water goes on supplying OH and H ions and HCl is generated. An inventory of the solution as the reaction progresses would show something like the following:

1. Some dissociated $SnCl_4$, giving Sn and Cl ions.
2. Some dissociated HCl giving H and Cl ions.

3. The stannic compound resulting from hydrolysis, not dissociated (say).

4. H_2O, very slightly dissociated, giving H and OH ions.

5. Non-dissociated $SnCl_4$.

6. Non-dissociated HCl (very small amount). Only 1 and 2, or the dissociated $SnCl_4$ and HCl, take any appreciable part in determining the conductivity of the solution.

We have, therefore, two variables in the problem, that is, the $SnCl_4$ is growing less as hydrolysis goes on, and thus more completely dissociated, while the HCl is gradually increasing and hence not so completely dissociated. The ultimate state of things would seem to be this: as the $SnCl_4$ is transformed the specific-conductivity of the solution is decreased (as far as it depends upon the $SnCl_4$) but as the $SnCl_4$ becomes less its dissociation is more complete, and its conductivity therefore increased. These tend to balance each other. As the HCl increases the conductivity of the solution increases; but as the solution becomes more concentrated with reference to HCl, the acid will not be so completely dissociated. Likewise these tend to balance each other.

(3) The *dilute* solutions of $SnCl_4$ hydrolyze with great rapidity; and when equilibrium is reached, they behave in every respect like dilute solutions of HCl, and in fact an equivalent amount of this acid is generated in the process of hydrolysis.

4. The conductivity of solutions of $SnCl_4$ of medium concentration increases slowly with time and *tends* toward a maximum value, namely, *the conductivity of a solution of HCl of the same equivalent strength.*

5. In the very concentrated solutions, the conductivity does not change with time. This does not show that the solution has not undergone any hydrolysis, for it gives a strongly acid reaction.

6. The stannic compound formed by hydrolysis *does not separate out in the more concentrated solutions*, and the hydrolysis of dilute solutions of $SnCl_4$ is practically complete long before the precipitation of the insoluble compound begins. At no time in the reaction does the stannic hydrate seem to take any part in determining the conductivity of the solution.

This compound is no doubt a colloid in dilute solutions, es-

pecially when first formed. We may look upon a colloid as a body in pseudo-solution, that is, a step between a true solution and an emulsion. It is known that the diffusion of colloids takes place slowly, the osmotic pressure is small and there is only a slight lowering of the freezing-point or raising of the boiling-point. With these facts and the fact that colloids do not conduct electricity, we conclude that they are not only larger than ordinary molecules, but that they are not dissociated into ions.

7. Attention was called in the first part of this paper to the abnormally large values of the depressions of the freezing-point as found by Loomis. For $m = 0.04$ ($m = 0.01$ according to Loomis) $\frac{\Delta}{m}$ was found to be 12.61. Considering that one molecule of $SnCl_4$ will give 4 HCl molecules (see reaction above) and that the HCl is completely dissociated in *very dilute* solutions, we shall have eight ions for every molecule of $SnCl_4$. These ions would take part in the conduction of the electricity and also act to lower the freezing-point. The maximum value of $\frac{\Delta}{m}$ would therefore be $(1.86 \times 8) = 14.88$. As stated above, Loomis found $\frac{\Delta}{m} = 12.61$ for a solution which he supposed to be 0.04 normal. He prepared this solution from a more concentrated solution made up according to Gerlach's table. According to this table the *gram-equivalent* solution of $SnCl_4$ has a sp. gr. of 1.0486 $\left(\frac{15^\circ}{4^\circ}\right)$. This was the strength of the solution used by Loomis. The writer found the sp. gr. of a gram-equivalent solution to be 1.0496 $\left(\frac{18^\circ}{4^\circ}\right)$, as may be seen in the first part of this paper.

Reducing Loomis' solution as prepared from Gerlach's table to $\frac{18^\circ}{4^\circ}$, it will be seen that our solutions differ by about two points in the third place of decimals. With these facts before us, Loomis prepared a solution with sp. gr. 1.0486 $\left(\frac{15^\circ}{4^\circ}\right)$, and according to my analysis it was found to be 11.5% *weaker* than a gram-equiva-

lent solution. Loomis' value for $\frac{\Delta}{m}$ (12.61) is therefore 11.5% too small. Its corrected value is 14.25.

A 0.04 gram-equivalent solution of HCl is 94.5% dissociated $\left(\frac{\mu_x}{\mu_\infty} = \frac{3400}{3600}\right)$. From this it follows that the theoretical value of $\frac{\Delta}{m}$ is $14.88 \times \frac{94.5}{100} = 14.06$. It is thus seen that this value corresponds well with the corrected value, 14.25, as found by Loomis.

8. Stannic chloride does not furnish an exception to the "dissociation theory"; for when account is taken of its hydrolysis, the phenomena manifested in its aqueous solution in connection with the electrical conductivity and the depression of the freezing-point are explained in accordance with this theory. On the other hand, however, it furnishes direct evidence against the "hydrate theory," for *the hydrate formed takes no appreciable part in the conduction of electricity*. Moreover, it is not probable that water sets HCl free, and then unites with the acid to form a second hydrate. We must still look upon the theory of electrolytes as founded by Arrhenius and others on van't Hoff's view of the nature of solution, as the one nearest in accord with the experimental data.

Finally, I wish to express my gratitude to Professor Loomis whose kindness and assistance have made it possible to carry out this investigation.

PHYSICAL LABORATORY, PRINCETON UNIVERSITY, March, 1899.

NOTES.

Gustav Wiedemann, whose death in Leipzig on March 24, 1899, has recently been announced, was born October 2, 1826, in Berlin. He was educated in the schools of his native city and later at the University of Berlin, where he became a pupil of Rose in chemistry, of Dirichlet in mathematics, and of Magnus, Dove and Mitscherlich in Physics. There were no university laboratories for physics in those days, but Wiedemann with a few other favored students, among whom was Helmholtz,[1] was fortunate enough to be admitted to the private laboratory of Magnus. In 1847 he received the degree of Doctor of Philosophy and in 1851 was enrolled as a Privatdocent in Berlin. In the latter year he married Clara Mitscherlich, a daughter of the physicist.

Wiedemann served for nine years as professor of physics at the University of Basle (1854 to 1863); he then taught the science for three years in the Polytechnic School at Brunswick, and in 1866 became successor to Eisenlohr in the Polytechnic Institute at Karlsruhe. In 1871 he was appointed professor of physical chemistry at Leipzig. In 1877 Hankel, who had been for many years director of the Physical Institute of that University, was retired on account of old age and Wiedemann became professor of physics and director of the Institute. This chair he occupied until his death.

Wiedemann is best known, perhaps, as the author of the compendious treatise on electricity which appeared in two volumes under the title *Die Lehre vom Galvanismus* (Brunswick, 1860 to 1863). It was subsequently rewritten and greatly enlarged as the growth of the subject of electricity demanded and was re-issued under a new name (*Die Lehre von der Elektricität*), in 1882. Still another edition, further revised and largely rewritten with the coöperation of the author's son, Professor E. Wiedemann of Erlangen, was in progress, and two volumes had appeared, at the time of the father's death.

When Professor Poggendorff, who for fifty-three years had conducted the *Annalen der Physik und Chemie*, died, the editorship of this famous periodical was placed in the hands of Wiedemann, and he remained its editor up to the time of his death, during which period sixty-seven volumes were issued. In addition to his labors as editor of the *Annalen* and as author of the treatise on Electricity, a life work in itself, Wiedemann carried on numerous investigations in experimental physics, and particularly in the domain of magnetism. His determination of the con-

[1] See Helmholtz's tribute to Wiedemann in Vol. 50 of the Annalen (1893).

ductivity of metals carried on in colaboration with Franz has become classical. It was in these experiments that electrical methods were first used for the determination of the distribution of temperatures. As a lecturer upon the elements of physics and of chemistry Wiedemann was noted for the clearness and simplicity of his exposition and for a delightful fluency and ease of diction. He had personal acquaintanceship with many of the famous experimenters of the first half of the century, and the inexhaustive fund of anecdote concerning them and their work was a delightful and, historically speaking, valuable element of his lectures. He treated physics from the point of view of the chemist rather than of the mathematician, and chemistry very largely from the standpoint of experimental physics.

Although he was for many years professor of physical chemistry in the University of Leipzig he did not deal with that subject as it is now treated. The science in its modern sense had scarcely been developed. He was director of two laboratories in the old University Quadrangle on the Augustus Platz in Leipzig; a chemical laboratory and a laboratory of physics. These were always held distinct, although the courses given in them overlapped to a great extent. The work done in both of them, like that of Bunsen in Heidelberg, covered much the same ground as the physical chemistry of the present day, but while it was not physical chemistry in the modern sense of the word it was, at least, useful in that it helped to make the newer science possible. E. L. N.

Wilhelm Gottlieb Hankel, who died in Leipzig, February 18, 1899, was professor of physics at the University of Leipzig for fifty years. Hankel was born May 17, 1814, at Ermsleben, Germany. He studied at the University of Halle where he received the degree of Doctor of Philosophy in 1839. For ten years, subsequently, he was a teacher in the *Realschule* of that town and professor in its University. In 1849 he was called to the chair of physics at the University of Leipzig. The period of Hankel's activity as a man of science lies chiefly between 1839, when he published as his thesis on the *Thermo-electricity of Crystals*, a field in which he was to become an authority, and 1870. His memoirs covered a wide range, but he is best known for his work upon the Electrical Properties of Crystals. He continued to lecture at Leipzig until 1887 and to publish occasional memoirs in the *Annalen* and in the Transactions of the Saxon Academy of Sciences. In that year he was retired from active service on account of old age and was succeeded by Wiedemann. These two men of science, Hankel and Wiedemann, whose loss we deplore, died within a few weeks' time of one another. Experimental physics at Leipzig has been in their hands for half a century and for forty years of this long period Hankel was the head of the *Physical Institute* of that university.

E. L. N.

NEW BOOKS.

Matter, Energy, Force and Work, a Plain Presentation of Fundamental Physical Concepts and of the Vortex-atom and other Theories. By SILAS W. HOLMAN. 12mo. Pp. xiv + 257. New York, The Macmillan Co., 1898.

This book is more than its title would indicate, being an attempt to re-formulate the fundamental physical concepts so as to bring them more into accord with the prominence of the conception of energy in physical science and with the advances recently made in the theory of the constitution of bodies.

As fundamental concepts are those in terms of which fundamental hypotheses or axioms are expressed, the re-formulation of concepts should involve a similar treatment of axioms. That this is desirable, the author does not seem to recognize; for while the concepts are treated with great elaboration, no systematic attempt is made to formulate the appropriate axioms. The reader, therefore, requires to find out for himself what changes in axioms the new concepts would render necessary.

After a short chapter on motion, which is conservative, indeed retrogressive, in character, the concept of energy is introduced. It is defined as "power to change the state of motion of a body," the following, among other comments being made: (1) "Energy stands to change of state of motion as cause to effect," and (2) "Whenever change of state of motion is in progress, there energy must be in action." The author holds, and considers it of importance, that according to his definition it is energy only that can properly be said to produce change of motion; but while this position is consistent with (1), it seems to be inconsistent with the definition itself, since mere power to change can hardly be said to produce change, and with (2) also, which would make energy *in action* the essential condition.

Energy being thus defined anew, the author devotes a chapter to showing that all forms of energy in the old sense will also be forms of what we may call Holman-energy.

Force is now introduced as "that action" ("process, mode of acting," etc.) "of energy by which it produces tendency to change in state of motion of bodies," the context showing that "tendency to change" includes its actual occurrence. Force is thus one or other of two processes, which are apparently assumed to be the same, and according to the author (who considers this also to be important), it (1) can-

not be said to be an "entity" in the same sense as energy can, (2) cannot be said to act, though energy can, and (3) can be produced by nothing but energy. But he does not show how mere power can with any propriety be said either to be an "entity" or to act, or how a mode of acting can be said to be produced by a power to change motion.

The quantitative aspect of energy is now reached; and here the author meets with a difficulty inherent in his mode of definition. The practice of defining quantitatively he holds to be "inadmissible in a fundamental treatment," "however harmless in mathematical physics." As his definition of energy is accordingly entirely qualitative, nothing quantitative is to be got out of it. He gets over the difficulty by means of the following "axiom:" "To accelerate equally from rest the free motion of a constant body at different times, equal quantities of energy must be imparted to the body." This, however, is not an axiom merely, for the term, quantity of energy, not having been defined, the statement, as a generalization of experience, is without meaning. It is an axiom in part, for it assumes that under the given conditions equal somethings are imparted to the body; and it is a definition in part, for it tells us what the term equal-quantities-of-energy is to mean. Armed with this axiom-definition the author appeals formally to experience, imagining experiments made with a machine by the aid of which moving bodies can exhaust their motion-changing power in the production of acceleration in a standard body; and (to sum up his results) he finds (1) that if different bodies with different velocities produce the same acceleration in the standard body, and thus afford evidence of the existence of equal quantities of energy, it is possible to attach to the different bodies numerical values K_1, K_2, etc., such that if V_1, V_2, etc. are the velocities of the bodies, $K_1V_1^2=K_2V_2^2=$etc., and (2) that the K's are the same, whatever the time of the observations and whatever the acceleration produced in the standard body may be. These constants K, he calls the kinergeties of the bodies. He then assumes that the kinergety of a body is proportional to the quantity of its kinetic energy when it has a given velocity, *i. e.*, he defines quantity-of-kinetic-energy in terms of kinergety. Thus he obtains two equations: $K \propto 1/V^2$ when H (*i. e.*, Holman kinetic energy) is constant, and $K \propto H$ when V is constant; whence $H \propto KV^2$.

As kinergety and mass (in the ordinary sense) are both quantities which have at all times the same value for the same body, they are proportional to one another, as also consequently are kinetic Holman-energy and kinetic energy. The author assumes throughout the book that kinergety and mass are proportional; but as his "mass" "is nothing more than a verbal substitute for the words quantity of matter," the assumption of their proportionality is quite gratuitous, if it has any meaning at all.

We are next introduced to the phenomena of transference and transformation of energy and the law of conservation to which they are subject. The law, as formally stated, is the law of conservation during transference and transformation only, and does not assert conservation during residence in a body or medium; but the context shows that this restriction is not intentional. Sketches are given of the historical development of this generalization and of the experimental evidence on which it is based, and some instances of transformation are considered. It should be noted that the law of conservation as historically developed, applies to energy as ordinarily defined, not to Holman-energy. And indeed as quantity of non-kinetic Holman-energy has not yet been defined, a law of conservation of Holman-energy, if stated, would have no meaning. The author, however, evidently intends to assert the conservation of Holman-energy as a fundamental axiom. For him, therefore, the law is at this stage, in part a definition, quantity of Holman-energy of any form being tacitly defined as equal to the quantity of kinetic energy into which it is transformable, and in part hypothesis, the quantity of kinetic energy into which it is transformable being assumed to be independent of time and mode of transformation.

The specification of force presents a difficulty; for as force is a mere process or mode of acting, one does not see why it should have direction or place of application or magnitude. It is assumed, however, to have all three; and it is asserted (1) that the direction of the mode of acting is the direction in which the body subjected to it would move if free, (2) that the point of application is the point at which the mode of acting is applied, and (3) that the magnitude is "naturally measured by the rate [*i. e.*, space rate] at which energy is imparted." The critic naturally holds that the direction, point of application, and magnitude of force have been defined quite independently of the definition of force itself. It follows, by the aid of these supplementary definitions, that Holman-force is proportional to the product of kinergety into acceleration, and therefore to the product of mass into acceleration, and therefore to ordinary force.

Work is defined as "any process of transference or transformation of energy," and like force is thus relegated to the limbo of non-entities. It is a process, "as force is, but of a different nature." If the body acted upon has sufficient freedom of motion, "the energy will both exert force and perform work." Thus in such a case energy (power to change motion) produces two processes of different nature. This view certainly does not conduce to clearness; but it admits of subtle language distinctions, as, *e. g.*, that it is permissible to say: work done under or against a force, but not to say: work done by or under the action of a force. One wonders how work, a process, can be said to be done at all, and if it can, why the other process, force, cannot be said to be done also.

The context contains a curious modification of the definition of work, viz., that the word transference is employed in it in the sense of imparting from one portion of substance to an adjacent one. The author apparently regards the conception of work as not applicable in distance-action treatments of physical problems except in cases in which transformation of energy only is involved. But there is nothing in his concepts to prevent their being employed both in distance-action and in contact-action modes of treatment.

It is asserted to be "evident from the nature and definition of work that it is to be measured by the quantity of energy transferred or transformed," and therefore by the product of Holman-force, and consequently of ordinary force, into co-directional displacement. As we know nothing of the nature of work except from the definition, this evident-ness cannot be admitted. Thus in reality a quantitative definition has again been superposed upon the original qualitative one.

Finally the term potential energy is used to denote energy which either is not, or is not known to be, kinetic, and its treatment will thus be obvious.

The closing chapters of the book contain sketches of the kinetic theory of gases, Le Sage's theory of gravitation, and the vortex-atom theory of the constitution of bodies. In the light especially of the vortex-atom theory, the author is led to distinguish between "primary substance," devoid of energy, to which he would restrict the term matter, and "substance," specifically so called, resulting from the association of energy with matter. The properties of substance are the properties of bodies, which are bounded portions of substance. The properties of "matter" he endeavors to get at by a process of exhaustion; but as might be expected, he is able to reach no definite conclusion; for the properties of the primary substance are to be determined not by ratiocination, but by investigation. If we must ascribe properties to it at all, at present, they must be considered to be the properties of a perfect fluid, these being the properties that the vortex-atom theorist finds he must ascribe to it in order to account for physical laws.

"Matter" is asserted to be quantitative; and the term mass is proposed as a synonym for quantity of matter, quite regardless of two facts (1) that this term is already almost universally employed in a quite different sense, and (2) that as yet there is no concept, quantity of matter, to require a name. This second objection is met by assuming (*i. e.*, defining) quantity of matter as proportional to quantity of substance, itself as yet a mere phrase. Quantity of substance is next assumed to be (*i. e.*, defined as) proportional to kinergety. Hence quantity-of-matter becomes proportional to kinergety also, and both it and quantity-of-substance, proportional to weight at one place. The quantities-of-substance

of two bodies may thus be compared by means of the balance; and it is proposed that when so determined they shall be called the weightals of the bodies.

This conception of weightal the author hopes will bring to an end the controversy between chemists and physicists as to the use of the terms weight, mass, atomic weight, atomic mass, etc. Neither mode of expression, according to the author, is justifiable, weightal, atomic weightal, etc., being the only defensible terms; and he holds this on the ground that what the chemist means by weight is quantity-of-substance. The chemist, however, knows nothing of "quantity-of-substance." He has found it possible to account for phenomena by assuming that his elements enter into combination in the form of little bodies which have a definite relation to one another with respect to their weights (combination must occur at one place), and have, therefore, the same relation with respect to their masses. Obviously, therefore, atomic weight and atomic mass are equally appropriate terms, even if the term weight be restricted to its sense of force. Atomic weightal would be justifiable also; but if the chemist and physicist quarrel about the two terms they have, what may they not be expected to do if given a third!

So far then as the writer is able to judge the author cannot be said to have been successful in re-formulating the physical concepts. He makes no use of his formal definitions except to draw from them precepts, which in some cases refuse to be drawn, as to what we should say and refrain from saying; and as these definitions form really no part of his system, which would stand without them, even those precepts which are deducible from them are not binding. Though the independent quantitative definitions, with the axioms expressed in terms of them, form a complete statement of the foundations of dynamics (the axioms employed being the constancy of kinergety and the conservation of energy, which in hypothetical content, are equivalent to the axioms ordinarily employed), the definitions and axioms are so inextricably intermingled that the axioms require to be enunciated piece-meal. The equations by which the axioms are expressed are practically identical with those derived from the axioms ordinarily employed; and there is thus no gain of facility in the discussion of physical problems. While, therefore, the proposed system of dynamical doctrine has no points of superiority over the old system, it has points of distinct inferiority.

Nevertheless the book as a whole is one from which the reader who is acquainted with the current dynamics will derive considerable benefit. For apart from the stimulus to be gained from looking at things from a new point of view, he will find scattered through the work interesting discussions of such topics as resistance to acceleration, the mechanism of the transference of energy, the possibility of all energy being ultimately

kinetic in form, and many others. The sketches of the theories of the constitution of bodies, especially of the vortex-atom theory are admirable pieces of exposition; and the critical discussions of these theories, as well as their application to the discussion of such subjects as the nature of chemical energy, are characterized by insight and originality and are worthy of careful consideration. In fact all parts of the book in which the author discusses physical questions are of value. It is only when he endeavors to lay foundations which shall be more fundamental than those of mathematical physics, and must therefore be laid in the metaphysical region, that as a writer on physics he lays himself open to seriously adverse criticism. J. G. MACGREGOR.

Harper's Scientific Memoirs. Vol. III. Röntgen Rays. Memoirs by RÖNTGEN, STOKES and J. J. THOMSON; translated and edited by GEORGE F. BARKER, LL.D., pp. 76. Vol. IV. Modern Theory of Solution. Memoirs by PFEFFER, VAN'T HOFF, ARRHENIUS and RAOULT; edited by HARRY C. JONES, Ph.D. Pp. 134. New York, Harper & Brothers. 1899.

In Professor Barker volume, translations of the original papers of Röntgen are appropriately followed by Stokes's suggestive lecture on the nature of the phenomena. The value of the volume would have been further enhanced, perhaps, if a larger amount of space had been allotted to the valuable work of J. J. Thomson in this field.

The memoirs selected for translation in Professor Jones's volume are well chosen. They give the reader who has not followed the newer work in physical chemistry a satisfactory glimpse of the modern theory of solution.

E. L. N.